PROJECT FINAL REPORT

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4.1 Final publishable summary report

1.- Executive summary

Traditionally fisheries management has been develop under a single species approach, where interactions among species are disregarded. This has been the case also in the Northwest Atlantic Fisheries Organization (NAFO) convention area. However since the massive collapse of cod stocks in the Northwest Atlantic, and especially since early 2000s, the Ecosystem Approach to Fisheries EAF management approach is being promoted, which was finally stated with the formation of the Working Group for Ecosystem Studies and Assessment (WGESA). One of the main topics in the roadmap of the WGESA is the development of multispecies models that are planned as one of the key elements in the management framework devised by the scientific council of NAFO for an EAF.

The Flemish Cap is a deep water mountain, with a high degree of isolation (minor migrations), and relative simplicity. Cod, redfish and shrimp are very important commercial species with strong trophic interactions that influence in population dynamic and interact with fishing activity. Hence, the Flemish Cap is an ideal case study to develop the first multispecies model in the NAFO area. GadCap deals with the development a Gadget multispecies model including cod, redfish, shrimp and their interactions with fishing activity, which will be integrated in the roadmap of the NAFO WGESA and the scientific council.

This project has been developed under the supervision of Daniel Howell, from the Institute of Marine Research of Norway, but also with the tight collaboration of scientist from the Spanish Oceanographic Institute (IEO) and the Institute of Marine Research (IIM) in Vigo (Spain), the Portuguese Institute for the Atmosphere and Sea (IPMA) in Lisbon (Portugal). These institutions have contributed with their scientific experience and the necessary data to set and develop the model. Other institutions like the Marine Research Institute of Reykjavik and the Department of Fisheries and Oceans of Canada has also contributed in the development of GadCap.

For the development of the multispecies model a training program has been followed, where Dr. Daniel Howell has been the main instructor. In addition, this formation has been complemented with specific training courses imparted by the International Council for the Exploration of the Sea (ICES) and the EU Joint Research Centre. Outreach activities for the general public have been accomplished through a website, spreading in newspapers, radio and television programs. Dissemination into the scientific community has been was faced trough meetings with the most important scientific working group in multispecies assessment methods (the ICES WGSAM) and the ICES Annual Science Conference. However, due to its relevance, the most important meetings have been those of the NAFO WGESA.

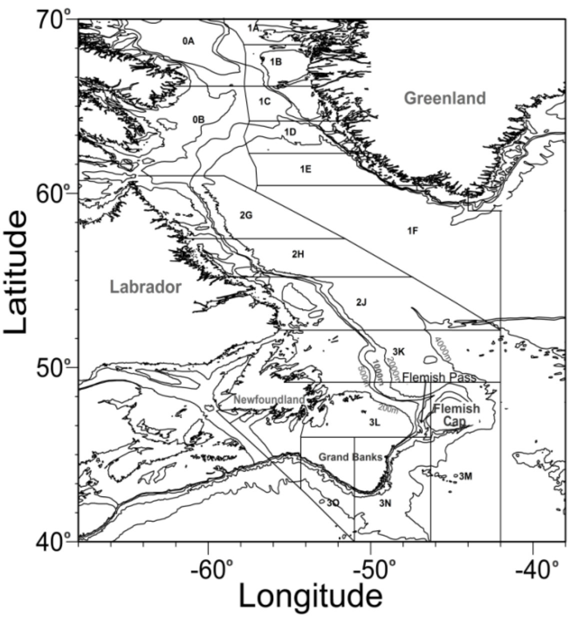
The resulting model has allowed quantifying the interactions between cod, redfish and shrimp in the Flemish cap, but especially their interaction with fishing activity. It has also permitted the estimation of multispecies maximum sustainable yields msMSY, a key element in the EAF. These results clearly indicate that disregarding the species interactions in the assessment of the Flemish Cap cod, redfish and shrimp would lead to serious underestimates of both the magnitude and the variability of natural mortality. This would involve an overestimation of the exploitable biomass in the short-term projections supporting management decisions, both by an excessive positivism in relation to the future survival of successful recruitments and the overestimation of survivorship for the fishable part of the stock. Meanwhile, it has been also shown that due to the prey-predator size relationship and the dynamic of prey-predator stock populations induced by variable recruitment, trophic interactions have a high degree of plasticity and are beyond of being only species interactions but size-modulated specific interactions. This should be seriously considered when evaluating the effect of a predator on a prey stock, otherwise the assessment of predation mortality could be misleading. In the same way, the multispecies model developed in this work presents a very suitable tool not just to understand the importance of predation, fishing and recruitment as drivers in the dynamic of the Flemish Cap system but also to quantify the shape and magnitude of species interactions as well as synergies among drivers, which could be used to support the stock assessment in the Flemish Cap.

The successful development of GadCap has opened new possibilities to continue with the development of the EAF in NAFO. Due to the capacity of this multispecies model to simulate complex interactions and feedbacks between the modeled stocks, it appears as an ideal operative model to be used for risk analysis in a management strategy evaluation framework for the Flemish Cap, and new projects are been developed in this line.

2.- Summary description of project context and objectives

Traditional approaches to fisheries management consider species as independent populations and are managed under this vision, i.e. from a single species approach. However, it has been proved that juveniles of many fish species support an intense predation rate, which may result in overestimates of stock-biomass per recruit by the single species models. This may favour declines in population or even the collapse of the stock, which could not being predicted by single-species models. Since 1950´s worldwide collapse of several marine stocks worldwide as result of an increasing fishing pressure raised the awareness about the limitation of resources and the increasing need of improving and applying a ecological knowledge to fisheries management. The massive collapse of all the Northwest Atlantic cod *Gadus morhua* stocks since 1990, including the Flemish Cap cod stock (Figure 1) triggered the change of fisheries management toward a precautionary approach, with higher multispecies and ecosystem considerations.

Historically, since the discovery of North America in 1497, the Northwest Atlantic cod stocks, highly abundant in these waters, became of extreme importance for European fleets. Since 1960, when declared catches information started to be collected, until 1978 when the Canadian Exclusive Economic Zone (EEZ) was established, total landings by the European fleet averaged 1 million tons, 70% of which was cod. Since 1978 foreign fleets were confined to ground fishes located out of the EEZ, among them the Flemish Cap (Figure 1). During these years catches were mostly constituted by cod and redfish *Sebastes* sp. until the massive collapse of all Northwest Atlantic cod stocks in the early 1990's. Since then, fishing was mostly focused on Greenland halibut *Reinhardtius hippoglossoides* and Northern shrimp *Pandalus borealis*.



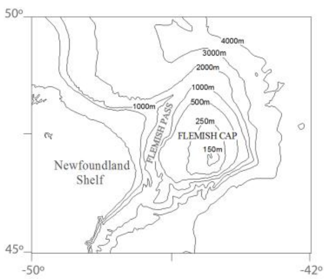


Figure 1.- The Flemish Cap is located within the regulatory area of the Northwest Atlantic Fisheries Organization (NAFO), corresponding to the Division 3M (left panel). The Flemish Pass, a channel deeper than 1100, separates the Flemish Cap from the Grand Banks of Newfoundland (panel below).

Since 1949, the Northwest Atlantic Fisheries Organization (NAFO, originally ICNAF) is in charge of the rational management and conservation of most fishery resources in the Northwest Atlantic, with the EU as one of the main contracting parties. Up to date, exploited species are managed under a single species approach in NAFO. However in 2008 the NAFO Working group for Ecosystem Studies and Assessment (WGESA) was created with the mission of providing advice in issues like Vulnerable Marine Ecosystems, fisheries production potential, eco-regions delimitations and very importantly, the influence of species interactions in the assessment of stock dynamic and management decisions.

The Flemish Cap is a deep water mountain located in NAFO area 3M (Figure 1). Two features provide high degree of isolation to the Flemish Cap marine populations. First, the cap is separated from the Newfoundland shelf by the Flemish Pass (Figure 1), a channel with depths beyond 1100 m. Second, a quasi-permanent anti-cyclonic gyre dominates the oceanography over the Cap producing a retention effect on eggs and larvae that would eventually stay over the Flemish Cap and recruit to the population. Species interdependence in the Flemish Cap has been just recently evaluated, and results showed a clear influence of cod predation in the dynamic of the redfish and shrimp stocks, while redfish has a strong influence in shrimp. Hence, it seems of great relevance the development of multispecies models in the Flemish Cap, evaluating the importance redfish-shrimp-cod interactions in a context of fishing activity.

The relative simplicity (85% of total biomass hoarded by cod, redfish and shrimp), the above mentioned isolation and the long and high quality data series make the Flemish Cap an ideal candidate fishing ground to start with the development of new management approaches in NAFO. The WGESA is developing an innovative roadmap where total fisheries production potential is estimated based in primary production calculations and rates of transference between trophic levels. These estimations in conjunction with multispecies and single species models will be employed to estimate Maximum Sustainable Yield (MSY) values for the different stocks under management. This approach supposes a two side estimation of MSY, taking into account bottom-up and top-down forces in the ecosystem.

GADGET (Globally applicable Area Disaggregated General Ecosystem Toolbox) is a powerful and flexible framework that has been developed to model marine ecosystems within a fisheries management and biological context. GADCAP deals with the development of a GADGET multispecies model in the Flemish Cap. As an ecosystem model it includes cod, redfish and shrimp interactions, growth rates, maturation, mortality rates, space occupancy and recruitment variability. As a fisheries model with management aims it includes information about fleet, gear types, total catches, age and size distribution of catches by species.

Objectives

The main objective of GADCAP is providing alternative management strategies for the Flemish Cap by increasing the knowledge about joint population dynamic of cod, redfish and shrimp in a context of fishing activity and variable environmental conditions. To do this, the most relevant drivers will be integrated in a multispecies, multiarea and multifleet GADGET model.

Objective 1: Single species models
Assemble for cod, redfish and shrimp independent monospecific models considering all landings, biological and oceanographic data and survey indexes of biomass and abundance.
Objective 2: Multispecific model
Combine the three monospecific models to create a unique multispecies model that evaluates the predatory and competitive interactions between species but considering the combined effect of fishing on the different species.
Objective 3: Model projections

Project population dynamic and future state of all the species modeled under different recruitment levels, species interactions and variable fishing pressure.

3.- Description of the main S&T results/foregrounds

In GadCap, Gadget was used to model the interdependent dynamic of the Flemish Cap cod, redfish and shrimp populations over the period 1988-2012, the effect of fishing and other environmental factors. The version 2.2.00 was employed (http://www.hafro.is/gadget/index.html) to create an age-length structured multispecies model considering different fleets and sub-populations as well as their interactions. Cod and redfish were considered both as prey and predators; while shrimp was modeled as prey. In addition other groups from the zooplankton, as well as demersal and pelagic fishes were included as exogenous input variables in the model (Figure 1). In the absence of data about the influence of the availability of prey on recruitment, growth or mortality of predator species (cod and redfish), only the influence of predation on prey stocks was modeled.

The optimal weight given to each likelihood component was estimated with the function gadget.iterative, of the R package Rgadget, which follows the process described in Taylor et al. (2007).

The redfish stock was constituted by the populations of three different species: Sebastes mentella, S. fasciatus and S.marinus. However these three species were separated during the survey only after 1993, when the decline and futher collapse of cod was very advanced, which prevented from modeling the redfish in an specific basis instead of a genus basis. However, due to the important differences among sexes in biological processes like growth and maturation (Saborido-Rey, 1994), male and female sub-stocks were modeled separated. Cod was not split by sex in the model since no size distribution data by sex was available. In the shrimp stock sex was also considered, but unlike in redfish sex was not a fixed state over the entire lifetime but changed at a given length. Northern shrimp is born as male, and after a reproductive life as male it changes to immature female (female primiparous) (Bergström 2000). Sex change was modeled in the same way than the maturation process. All the modeled species were split into immature and mature sub-stocks (Figure1; Tables 1, 2 and 3).

For each modeled stock, the substocks the age and length range, and some other processes and parameters defining the structure for each single species model are outlined in tables 1, 2 and 3 for cod, redfish and shrimp respectively.

For all the three species the initial population was estimated as the number of individuals by age in year 1988. Recruitment was estimated annually for all the three species as the number of individuals at age 1 on 1st January. In the redfish stock, the estimated recruits were split into males and females assuming that 50% of individuals at age 1 belonged to each sex. The mean length and standard deviation at recruitment was fit annually for the cod stock, while for redfish three different periods 1988-1993, 1994-1997 and 1998-2012 were considered, and for shrimp two different periods, 1988-2003 and 2004-2012. As part of the Gadget performing, the mean length and standard deviation at age 1 are used to produce the size distribution at recruitment assuming a normal distribution.

The Von Bertalanffy growth model was used to define the growth curves for all the three species. For cod, the model was fit to the data annually, while for the redfish and shrimp stocks this model was fit for the same periods defined above for the size at recruitment. For each species the average standard deviation at age around the mean length was defined for the whole time period. In gadget the mean growth in length during a time step is estimated for each length group using the fit Von Bertalanffy growth function. Although Gadget can model all the processes in a monthly basis, in this model a 3 month framework (4 time steps by year) was considered instead. Length distribution around the mean are estimated according to the average standard deviation at age assuming a beta-binomial distribution. A unique length-weight relation was fit for all time steps and years.

Table 1.- Model structure, main ecological and biological features for cod.

	Immature	Mature_small	Mature_large
Period	1988-2012		
Time step	3 months		
Age range	0-12		
Length range (cm)	1cm-L50	L50-85cm	85cm-140cm
Length resolution	1 cm		
Fishing fleets	CT_I; CT_II;CG; EUs		
Residual mortality	Age1: 0.2		
Growth	Von Bertalanffy; annual estimate		
Maturation	Biannual maturation ogive		
Maturation date	4th timestep		
Recruitment	Annual estimate		
Age at recruitment	1		
Recruitment date	1st timestep		

CT_I and CT_II: cod trawl fleet 1988-1998 and 1999-2012 respectively. CG: cod gillnet fleet. EUs: EU survey; L50: Length at 50% probability of maturing.

Table 2.- Model structure, main ecological and biological features for redfish.

	Male_immature	Male_mature	Female_immature	Female_mature
Period	1988-2012			
Time step	3 months			
Age range	0-25			
Length range (cm)	1cm- L50 male	L50 male-60cm	1cm-L50 fem	L50 fem-60cm
Length resolution	1 cm			
Fishing fleets	RT_I; RT_II; ST; EUs			
Residual mortality	Age1-2: 0.1			
Growth	Von Bertalanffy; 3 periods			
Maturation	One maturation ogive		One maturation ogive	
Maturation date	4th timestep		4th timestep	
Recruitment	Annual estimate		Annual estimate	
Age at recruitment	1		1	
Recruitment date	1st timestep		1st timestep	

RT_I and RT_II: redfish trawl fleet 1988-1998 and 1999-2012 respectively; ST: Shrimp trawl fleet; EUs: EU survey; L50 male and L50 fem: Length at 50% probability of maturing for male and female sub-stock respectively.

Table 3.- Model structure, main ecological and biological features for shrimp.

	Male	Female_primiparous	Female_multiparous
Period	1988-2012		
Time step	3 months		
Age range	0-7		
Length range (cm)	0.05cm-L50 sex	L50 sex-L50 mat	L50 mat-3.8cm
Length resolution (cm)	0.05		
Fishing fleets	ST; EUs		
Residual mortality	Age1=0.2; Age2-7=0.1		
Growth	Von Bertalanffy; two periods		
Sex change	Bi-annual ogive		
Sex change date	4th timestep		
Maturation		Bi-annual ogive	
Maturation date		4th timestep	
Recruitment	Annual estimate		
Age at recruitment	1		
Recruitment date	1st timestep		

ST: Shrimp trawl fleet; EUs: EU survey; L50 sex: length at 50% probability change from male to female primiparous. L50 mat: length at 50% probability change from female primiparous to multiparous.

The probability of an immature individual to become mature in all the three species, and the probability of change of sex from male to female primiparous in the shrimp stock, was modeled using the equation:

$$P(l) = \frac{1}{1+e^{-4\alpha(l_i - l_{50})}} \qquad (1)$$

where $P(l)$ is the probability of maturing (or changing the sex in shrimp) at a given length l, l_i is the middle length of the length group i, l_{50} is the length at which 50% of the individuals become mature (or changing the sex in shrimp) in a given year, and α is a parameter to be estimated. It was assumed that all the three stocks mature or change from male to female in the last time step (4th time step) of the year.

The international commercial fishery in the Flemish Cap was modeled for cod, as two different fleets: trawl and gillnet. The longline fishery was not considered due to its low importance and the shortage of information. For redfish the pelagic and bottom trawl fishery were simplified to a unique trawl fishery due to the lack of information about total catches and seasonal size distribution of catches in the pelagic fleet. The shrimp fishery was also considered for the redfish stock due to the important by-catch of juvenile redfish during the 1990´s, especially before the introduction of a sorting grid. The only fishing gear targeting the shrimp stock was the bottom trawl.

Some degree of flexibility around the total catch was allowed for all the fleets considered in this study, including the survey fleet. Total catches were simulated in the model for each fleet and time step through the equation:

$$C_{sl} = E S_{sl} \Delta_t N_{sl} W_{sl} \qquad (2)$$

where C_{sl} is the catch in kg for a given species and length cell, E is the scaling factor for the stock that is to be caught, Δ_t is the length of the time step, N_{sl} is the number of individuals and W_{sl} is the mean weight of that species in the length cell. The parameter E was estimated annually for each commercial fleet, resembling the changes in effort over time. However for the survey fleets only one parameter was estimated for each species, in order to keep the effort constant over time. S_{sl} is defined by the suitability function and defines proportion of the length group that will be caught by the fleet, and as such the suitability values should be between 0 and 1.

The suitability function employed in the model was variable depending on the fleet. Trawl fleets were assumed to fit to a logistic suitability function of length:

$$S(l) = \frac{1}{1+e^{-4\alpha(l_i - l_{50})}} \quad (3)$$

where $S(l)$ is the proportion of the species at a given length l that is potentially caught by the fleet, l_i is the middle length of the length group I, l_{50} is the length at which 50% of the individuals are potentially fished, and α is a parameter to be estimated.

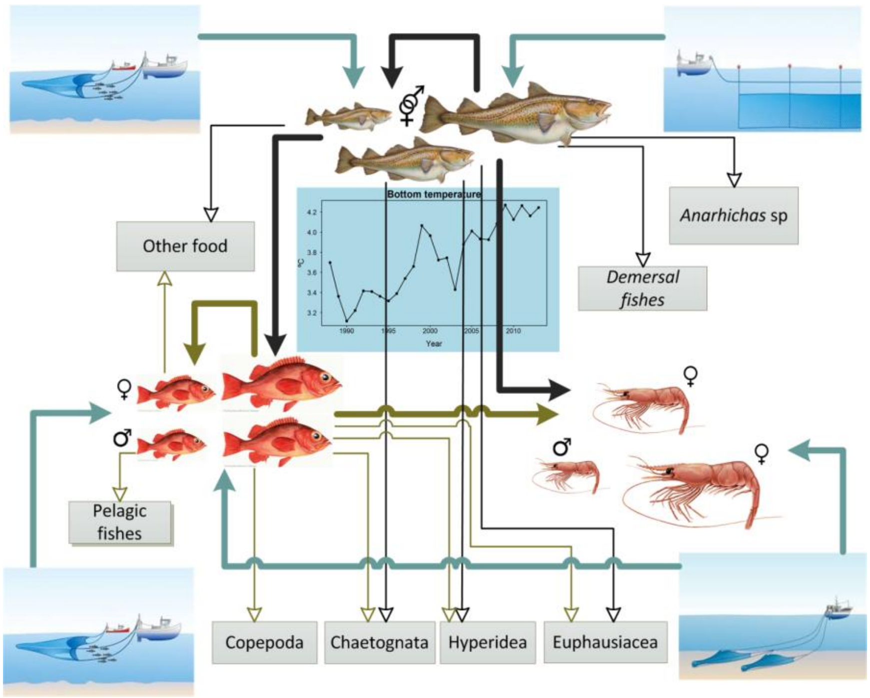


Figure 1.- Species interactions modeled in this study. Cod, redfish and shrimp are fully dynamically modeled, whereas species/prey groups in grey text boxes are incorporated as time series or constant values. The fleets fishing each species are also represented.

For the cod gillnet fleet and catches of redfish by the shrimp trawl fleet, the suitability curve was assumed to have a dome shaped relation with length, which follow the equation:

$$S(l,L) = \begin{cases} p_0 + p_2 e^{\frac{-\left(ln\frac{L}{l} - p_1\right)^2}{p_4}} & if\ ln\frac{L}{l} \le p_1 \\ p_0 + p_2 e^{\frac{-\left(ln\frac{L}{l} - p_1\right)^2}{p_3}} & if\ ln\frac{L}{l} \ge p_1 \end{cases} \quad (4)$$

where $S(l,L)$ is the proportion of the species at a given length l that is potentially caught by the fleet. L denotes the length of the predator, which is a meaningless concept when the predator is a fleet and takes a constant value, the average length of the species. p_0, p_1, p_2, p_3 and p_4 are parameters to be estimated that define the lowest value (assumed to be 0), the length range caught by the fleet, the maximum value (assumed to be 1), the left slope shape and the right slope shape respectively.

With equations 2, 3 and 4, total catches (numbers and biomass) by time step, fleet and species are estimated and distributed by length.

Due to the different pattern of exploitation of cod and redfish expected before and after the collapse of cod stock, the trawl commercial fleets for these species were split into two different periods, 1988-1998 and 1999-2012. Consistently, two different sets of parameters for the suitability functions were fit.

In the present model it was assumed that all the three modeled species stay in the modeled area during their whole lifetime, and that there are no differences by area in mortality (wheter, predation, fishing or residual mortality) or growth over the Flemish Cap. For this reason a unique area was considered for all the species.

The residual natural mortality (other than that due to trophic interactions) in shrimp was assumed 0.2 at age 1 and 0.1 at ages 2 to 7. For cod at ages 1, 2 and 3 (when cannibalism is more important) residual natural mortality was set as 0.1, 0.07 and 0.05 respectively. At ages 4 to 12, when predation was expected to be non-significant, the natural mortality values were taken from González-Troncoso and González-Costas (2014). In redfish natural mortality at ages 1-2 and 3-16 was assumed 0.1 and 0.05. For ages 17-25 residual values for natural mortality were taken from Efimov et al. (1986).

In the multispecies approach (trophic interactions), cod and redfish work as predator but also as prey (figure 1). Immature and mature cod preyed on the modeled preys: immature cod (cannibalism), redfish (immature and mature of both sexes), shrimp; and the non-modeled preys: hyperiids, euphasiids, chaetognaths, Anarhichas sp., pisces demersales and other food. Redfish preyed on the modeled preys: male and female immature redfish (cannibalism) and shrimp; as well as the non-modeled preys: copepods, hyperiids, euphasiids, chaetognaths, pelagic fishes and other food.

The present model has not been designed for the consumption of any prey having any effect on growth and survival of predators. The exceptions to this are 1) the direct effect of cannibalism, which by affecting the dynamic of the prey it affects the survival of juvenile stages of the predator; 2) the indirect effect that the abundance of alternative prey has over the intensity of cannibalism.

Total consumption by length, for both cod and redfish, was estimated annually for each time step using a bioenergetic model (Temming and Herrmann 2009). In Gadget, these estimates were used to model the consumption as a function of length and water temperature using the same model included in MULTSPEC (Bogstad et al. 1997). Once the average consumption by individual was modeled, the total consumption was estimated by multiplying by the number of predators in each length group, and summing over all groups (Begley 2005): $C_p(l,L) = \frac{N_L M_L \psi_L F_p(l,L)}{\sum_p F_p(l,L)}$ (5)

$$F_p(l,L) = (S_p(l,L) E_p N_l W_l)^d \quad (6)$$

$$\psi_L = \frac{\sum_p F_p(l,L)}{H\Delta_t + \sum_p F_p(l,L)} \quad (7)$$

where $C_p(l,L)$ is the total consumption of prey p of size l by the whole predator population at length L, which is determined by N_L, the number of predator in length cell L; M_L the maximum consumption for a predator of length L; $F_p(l,L)$ the consumption of prey p of size l by an individual predator in the length cell L; and ψ_L the feeding level at predator length L. In addition to the sum of

$F_p(l, L)$ for all prey species, ψ_L is dependent on the half feeding value H, the biomass of prey required for the predator consuming prey at a half the maximum consumption level. We assume that the total prey consumption by both cod and redfish is independent of the amount of available food, and hence, the half feeding value H was st to zero. $F_p(l, L)$ depends on the suitability function S_p; the prey energy content E_p; N_l the number of prey at length and W_l the average weight of prey at length l. Since M_L was estimated in Kilograms instead of Kilojoules, E_p was set as 1 for all prey species. The parameter d determines the shape of the functional response of predator consumption to the abundance of the prey. In this model d was set as 1, which means a functional response type II (asymptotic).

The maximum total consumption rate M_L (as kg/time step) by an individual predator was modeled as a function of length and water temperature as follow:

$$M_L = m_0 \Delta t e^{(m_1 T - m_2 T^3)} L^{m_3} \qquad (8)$$

The relationship between predator length and prey length was studied for all predator-prey interactions among the modeled species. For these interactions the suitability of a prey for a predator was modeled assuming a dome shape relation, the above mentioned Andersen function (equation 4). For a given predator size, there is a prey size for which suitability is maximum, and decay at both sides. The maximum suitability, the relation between prey and predator size, as well as the asymmetry of this curve will be determined by the set of parameters p_0, p_1, p_2, p_3 and p_4. For those predator-prey interactions with the non-modeled prey species a constant suitability function was assumed and hence, no variations with the predator-prey size ratio were considered.

Prey suitability is a relative index, with values for all the prey species being sorted and starting at 1 for the most preferred prey to the lowest value for the less preferred one. Suitability values are representative of the importance of a prey in the diet related with its relative importance in the ecosystem. These parameters as all the other parameters of the prey-predator size curve and the consumption model were estimated externally. Different grouping of years were explored for the estimation of the prey-predator suitability values that could represent changes in prey selection or accessibility to a predator.

Data

Most of the data employed in the present work have been obtained from the International European Union (EU) bottom trawl surveys, conducted annually on the June-July period since 1988. The surveys followed the NAFO recommendations (Doubleday, 1981) and consisted on a bottom trawl random stratified sampling design (Vázquez et al. 2013). This design allows estimating indexes of total abundance and biomass, as well as the size distribution in the whole bank for all the demersal species, with especial focus on the three species modeled in this work, and also by sex for redfish and shrimp. A detailed biological sampling was carried out for all the three species, consisting on sex, size, weight, age and maturity state, which allows the estimation of length-weight relationship, as well as sex change (for shrimp) and maturity ogives. Although the survey is not designed for pelagic fish species, it can be used as a proxy index of trend in total biomass.

Stomach content information for cod and redfish in Flemish Cap has been collected annually since 1993 as part of the sampling protocol of the EU Flemish Cap July bottom trawl survey, with the exception of years 2007, 2009 and 2011. During the EU survey, on each haul a maximum number of 10 stomachs were analyzed by 10 cm size class and sex for cod and redfish. On average, 500 and 900 stomachs have being sampled annually for cod and redfish respectively. This information was use to calculate the contribution of each prey (in percentage) over the total stomach content as well as the prey-predator length relationship.

Data on temperature was measured from surface to the bottom using conductivity-temperature-depth cast (CTDs). The bottom temperature for each CTD was estimated as the temperature at the maximum depth. The average surface and bottom temperatures was estimated annually for the whole Flemish Cap as the mean value of all CTDs.

Differences in redfish maturation by sex were modeled using the biological information collected during the Department of Fisheries and Oceans of Canada (hereafter DFO) surveys in the Flemish Cap during the period 1978-1985.

The Continuum Plankton Recorder (CPR) survey marine monitoring program of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS; website: http://www.sahfos.ac.uk) collected information from the Northwest Atlantic surface planktonic organism during the period 1991-2012. CPR data have being used to estimate a five years moving geometric average as semi-quantitative estimates reflecting long term patterns in copepods, hyperiids, chaetognats and euphausiids over this period.

The estimated average ecosystem potential production for the zooplankton and pelagic fishes (Koen-Alonso et al. 2013) was employed to estimate, in conjunction with the CPR and the EU survey index respectively, the total annual biomass of this groups over the Flemish Cap.

The information about total annual catches of cod, redfish and shrimp by the international commercial fishery in the Flemish Cap since 1988 was obtained from the annual reports of the assessment of these stocks published in the NAFO website http://www.nafo.int/publications/frames/publications.html. Annual catches were split into the different fleets and over seasons based in the information presented in the NAFO database STATLANT21B at http://www.nafo.int/data/frames/data.html. Size distributions were gathered from the research reports and the research documents published in the NAFO website http://www.nafo.int/publications/frames/publications.html. Due to the absence of detailed commercial fishing information from several countries fishing in NAFO, most of the information on size distribution and temporal allocation of catches over the year were compiled from the Spanish and Portuguese annual research reports. This is an acceptable assumption since Spain and Portugal are two of the four main countries fishing cod and redfish in the Flemish Cap. For shrimp, the Icelandic fleet was taken as the basis for the size distribution of catches.

Parameter estimation and model validation

Parameters in Gadget are optimized using a two-stage process, combining simulated annealing and a Hooke and Jeeves stepwise estimation procedure (Begley and Howell 2004). For each database a likelihood components was set. The sum of squares likelihood function was used for comparison of observed and modeled catches both for survey and commercial fleets. The same likelihood function was used with the size distributions likelihood components, as recommended by Taylor et al. (2007). The goodness of fit for the stomach content likelihood components was calculated using the SCSimple function by comparing the ratio of the consumption of different preys by a predator in the model to the observed proportions of each prey in the observed diet. The total likelihood score is the result of a weighted sum of the likelihood score of all the components in the model. The optimal weight given to each likelihood component was estimated with the function gadget.iterative, of the R package Rgadget (https://github.com/rforge/rgadget), which follows the process described in Taylor et al. (2007). A sensitivity test was conducted to confirm that an optimum was reached.

Model fit

Cod

The model produced values of biomass and abundance (including the recruitment index proxy, or smaller than 25cm individuals), as well as catches in kg for the trawl, gillnet and survey fleets, that were very close to the observed values (Figure 2).

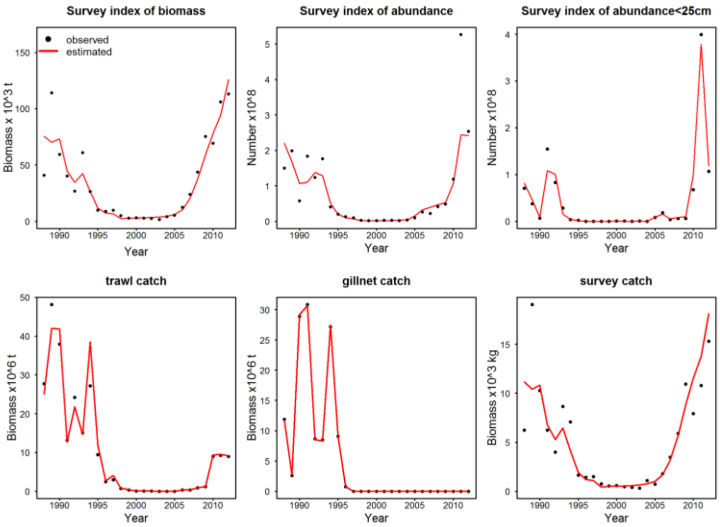


Figure 2.- Cod survey indexes (swept area method) of biomass, abundance and abundance of individuals smaller than 25 cm (from left to right in the first row), and catch in tones by the international trawl and gillnet fleets, and in kg for the EU survey fleet (left to right in the second row).

The estimated size distribution of catches showed also in general a high similarity with the observed distributions for the trawl and gillnet commercial fleets and for the survey fleet (Figure 3). However, in the trawl fishery there was a marked deviation from the observed size distribution since the reopening of the fishery in 2010, which could be related with a change in the pattern of selectivity of this fleet in the last years. It is interesting also to note that it seems that the survey fleet size distribution tends to estimate higher proportions of individuals at larger sizes than the observed values. This is especially shown in those years of high recruitments, like 1991 or 2010-2012. This fact may be potentially a reflection of two factors: 1) a removal of individuals larger than 50 cm in those years of high recruitments either as result of increased natural mortality or migratory processes; 2) a change in the catchability (maybe dome shaped curve instead of logistic) of larger individuals in those years of high abundance of juveniles. This will need to be explored in the future.

The maturity ogives by length were fit by the model in a two years group basis. The estimated proportion of mature individuals was in general very similar to that described by the observed maturity ogives (Figure 4), with the exception of year 1994.

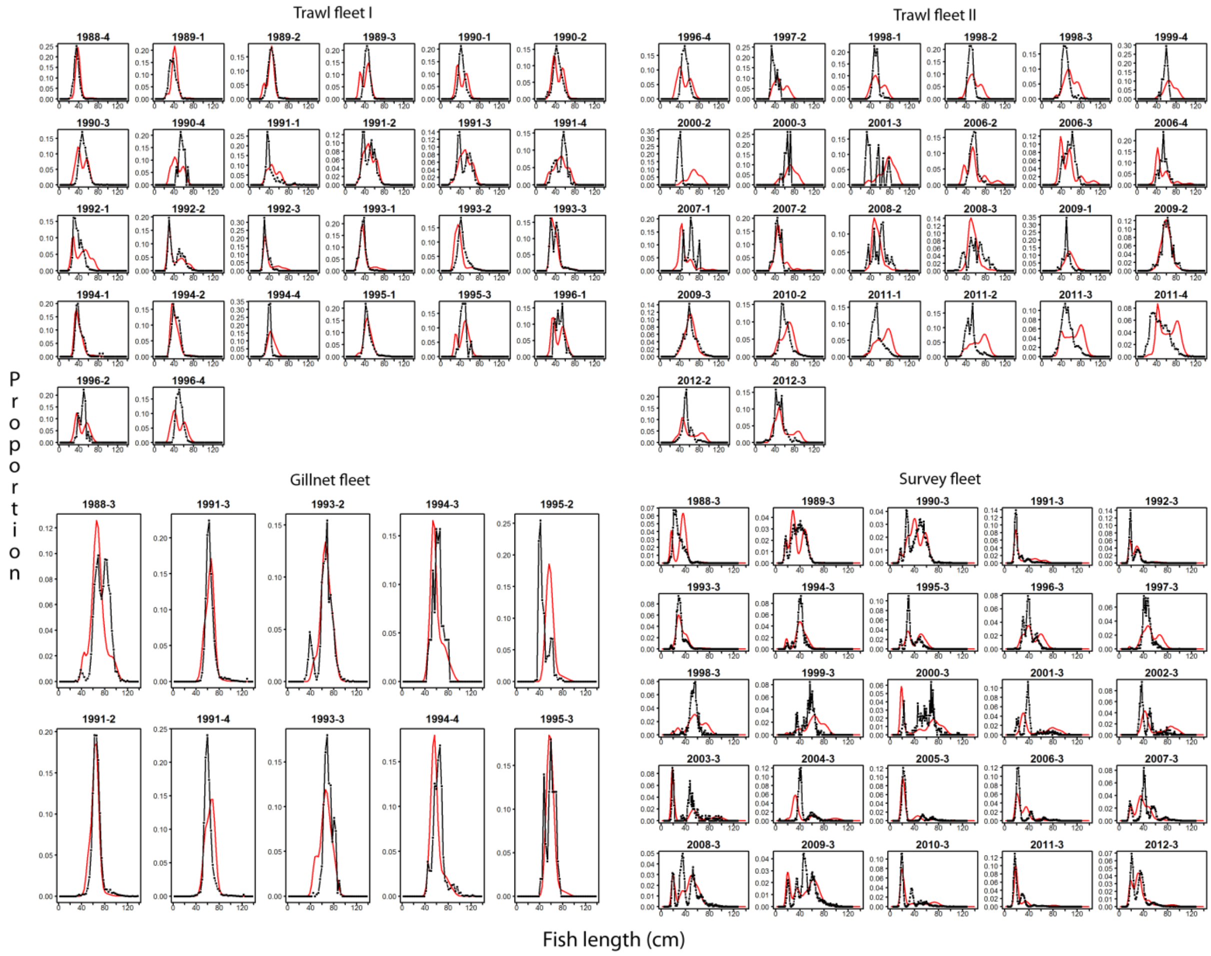


Figure 3.- Size distribution by fish length (in proportion relative to 1) of cod catches in the trawl (upper panels) , gillnet (bottom-left) and survey fleets (bottom-right). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red lines are the estimated values versus black lines which depicts the observed data.

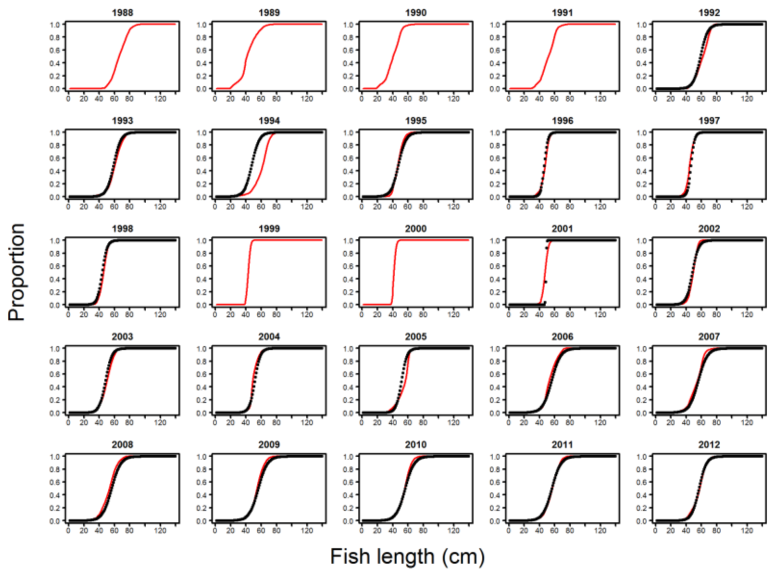


Figure 4.- Cod maturity ogives as probability, relative to 1, of being mature with total fish length (in cm). Estimated probabilities by the fit model in red color lines; Observed proportions in black color points.

<u>Redfish</u>

In the redfish stock, the output from model fit was very similar to the observed indexes of biomass, total abundance and abundance of individuals smaller than 12 cm length. However, in this case there was a higher deviation from the observed index of biomass which was also coherently shown in the EU survey total catch (Figure 5). The estimated catches by the model was very similar to the reported catches in the redfish and shrimp trawl fisheries.

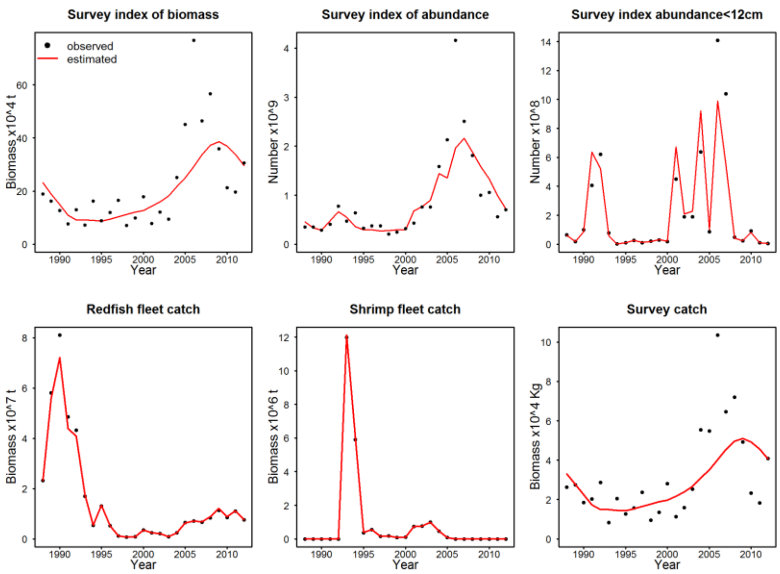


Figure 5.- Redfish survey indexes (swept area method) of biomass, abundance and abundance of individuals smaller than 12 cm (from left to right in the first row), and catch in tones by the international redfish trawl, shrimp trawl (as by-catch) fleets, and in kg for the EU survey fleet (left to right in the second row).

The size distribution of the redfish by-catch from the shrimp trawl fishery was very well fitted by the model (Figure 6). With the exception of a few seasons in some years, the size distribution of catches from the redfish trawl fishery was also well simulated. The size distribution of catches from the EU survey fleet was also in general well fit. However, it is interesting to note that in those years of high recruitments (as those of 1991 and 2001) the peak in the size distribution that belongs to individuals of size near to 30cm in the previous years (1990 and 2000) suddenly disappeared in the size distribution sampled during the survey. However the model estimates size distributions, as there was no any added source of mortality that remove this individuals from the population in 1991 and 2001 (and years after) still contained these large individuals. This fact, as already mentioned above for cod, may be suggested to be a reflection of either a removal of individuals larger than 30 cm in those years of high recruitments (as result of increased natural mortality or migratory processes), and/or a change in the survey catchability of larger individuals in those years of high abundance of juveniles. This questions need to be explored in the future and will probably require of directed research work as the analysis of the acoustic signal during the EU survey or specific analysis to evaluate the migratory patterns of redfish under different oceanographic and demographic conditions.

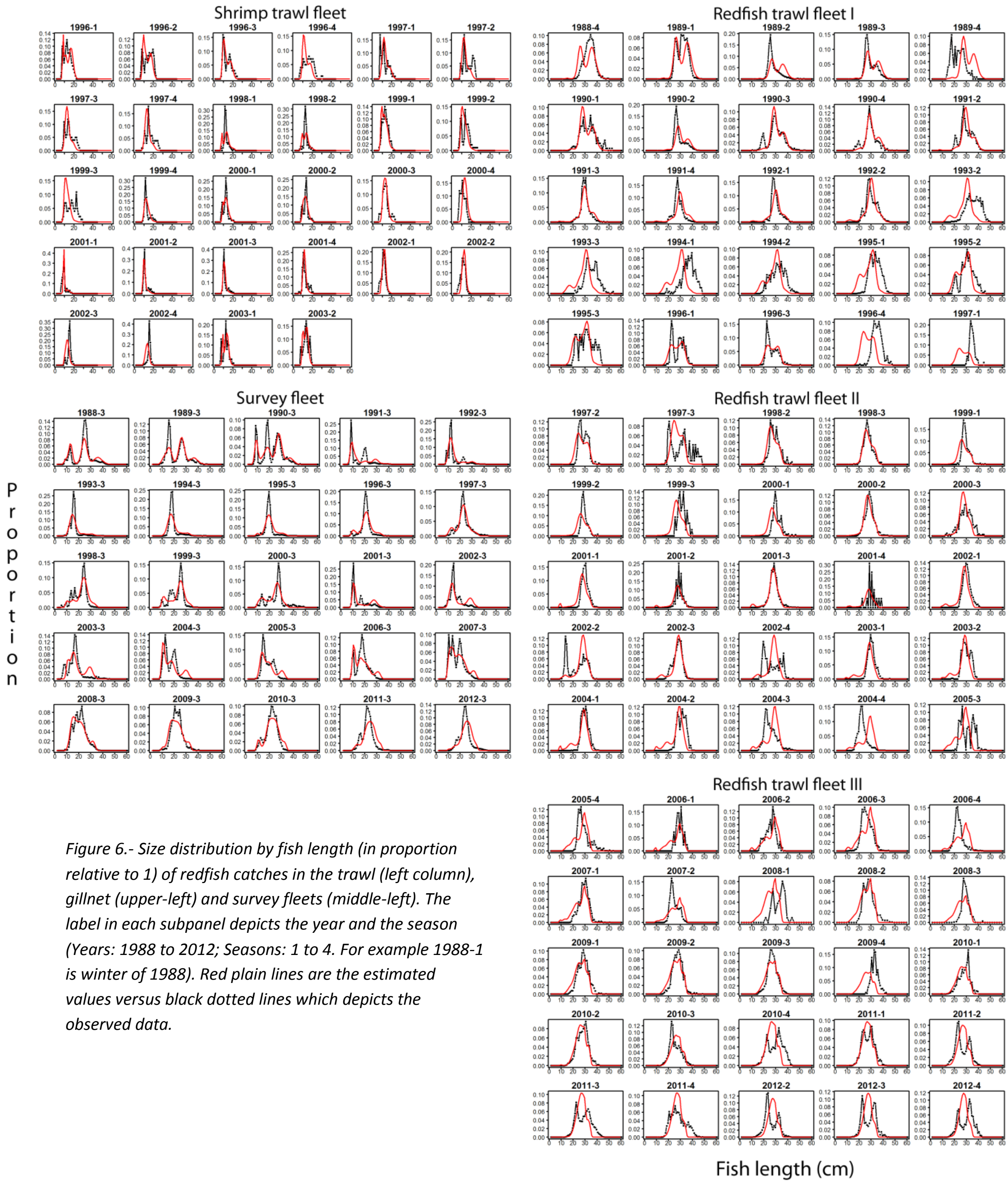


Figure 6.- Size distribution by fish length (in proportion relative to 1) of redfish catches in the trawl (left column), gillnet (upper-left) and survey fleets (middle-left). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red plain lines are the estimated values versus black dotted lines which depicts the observed data.

The maturity ogives were, as mentioned in the material and methods section, fit assuming a constant maturity ogive over time. As shown in figure 7 the observed proportion of mature individuals was well fit by the model.

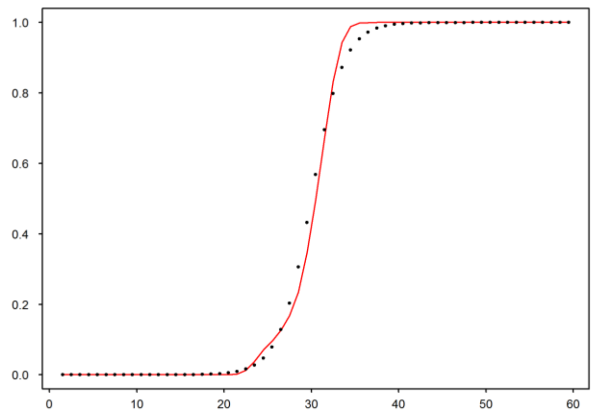


Figure 7.- Redfish maturity ogives as probability, relative to 1, of being mature with total fish length (in cm). Estimated probabilities by the fit model in red color lines; Observed proportions in black color points.

<u>Shrimp</u>

In this species, all the observed data for survey indexes of biomass and abundance, as well as the catches from the commercial and survey fleets showed a very similar pattern, and were well fitted by the model estimated values (Figure 8).

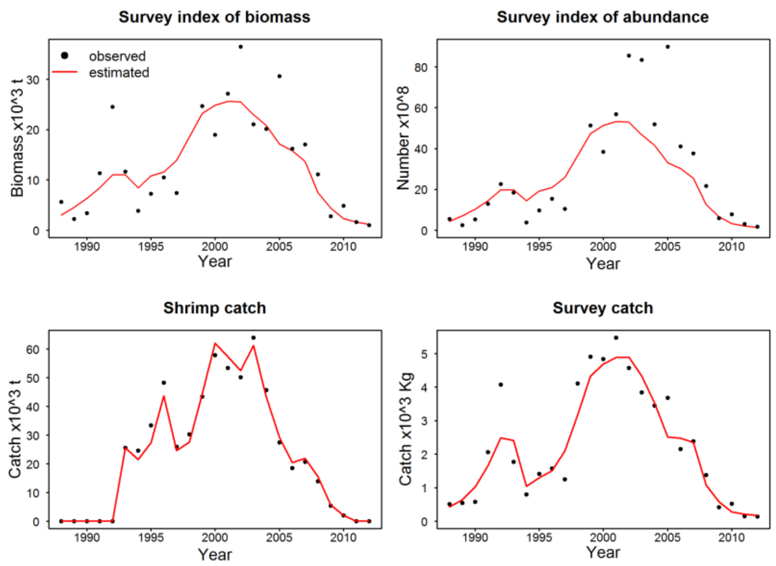


Figure 8.- Shrimp survey indexes (swept area method) of biomass (upper-left panel) and abundance (upper-right), and catch in tones by the international trawl fleet (bottom-left), and in kg for the EU survey fleet (bottom right).

The size distribution of the survey fleet (Figure 9) despite was globally well fitted, showed important deviations from the observed values, especially in the first and last year of the time series. Since the data from the shrimp trawl fleet was thoroughly sampled by the Icelandic fleet, and this size distribution was very well fitted by the model, the deviation in the survey fleet size distribution was considered not having a bad effect in terms of the shrimp model perform. In addition, it is known that the trawl gear of the survey, both due to its mesh size and its configuration is not the best design for shrimp.

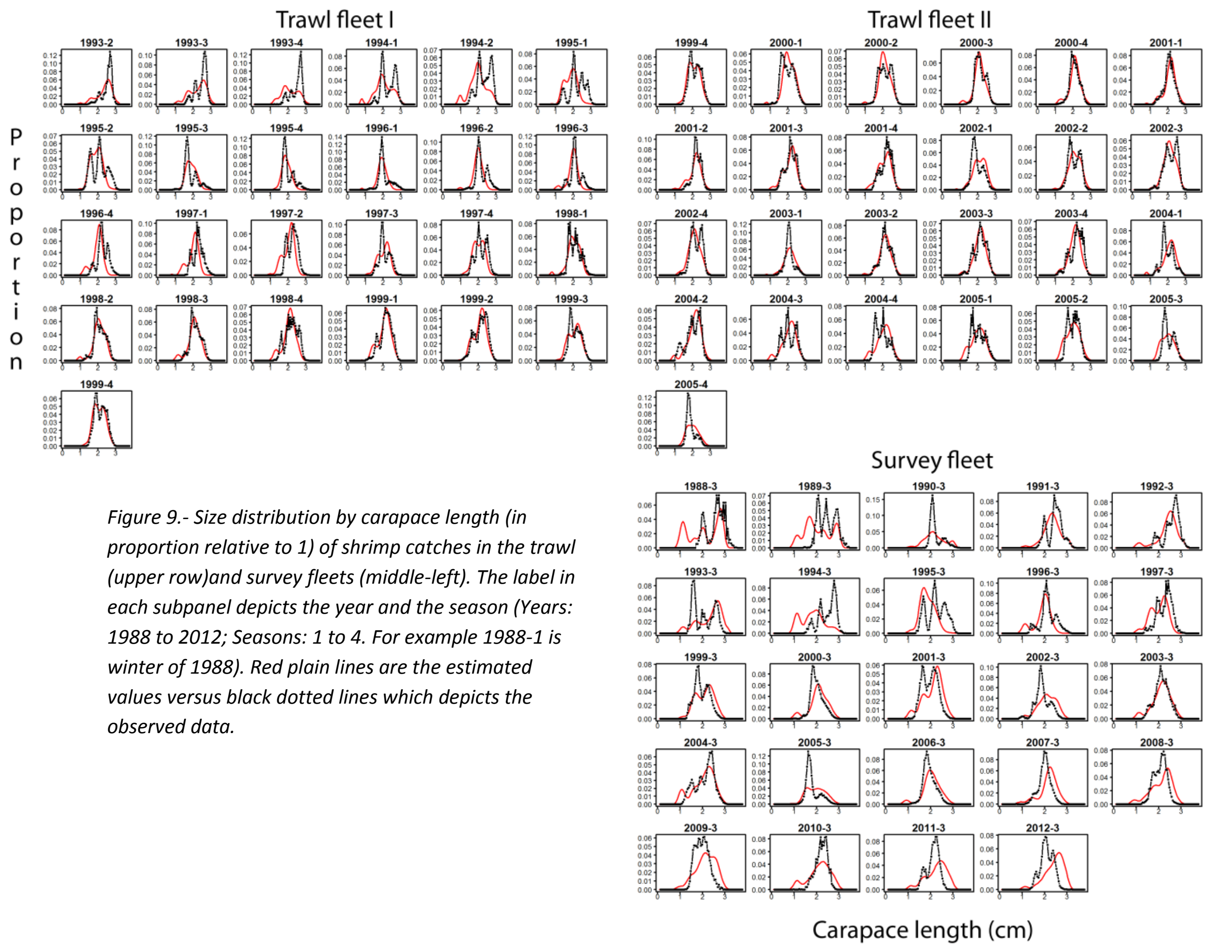


Figure 9.- Size distribution by carapace length (in proportion relative to 1) of shrimp catches in the trawl (upper row)and survey fleets (middle-left). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red plain lines are the estimated values versus black dotted lines which depicts the observed data.

The estimated proportion of males, females primiparous and multiparous was fit from year 1994 onwards by means of optimizing the parameters that defined the female maturity and sex change ogives. These estimated proportions showed some difference in relation to the observed values (Figure 10), especially in the last years. This could be improved in the future, but at this moment is expected to be of low impact in the results.

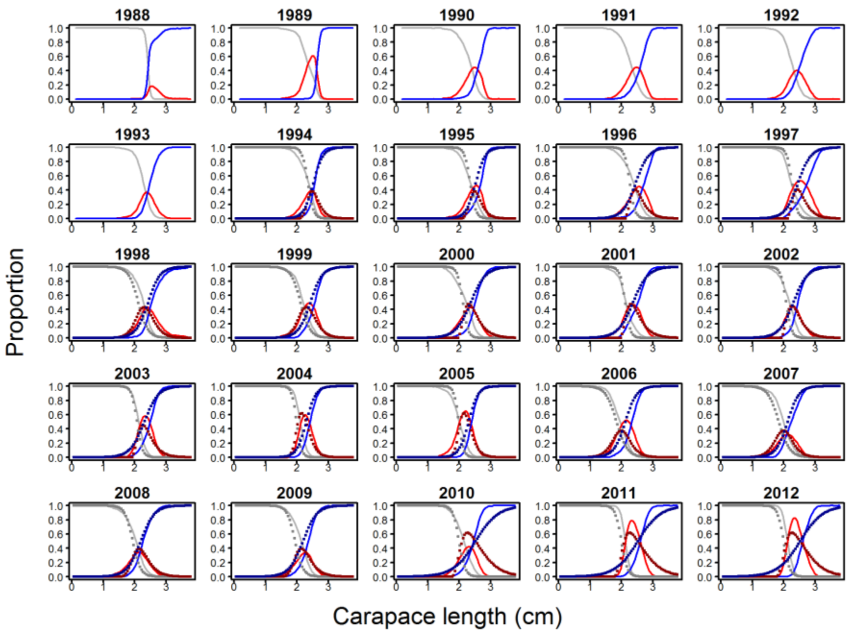


Figure 10.- Shrimp sex change and maturity ogives as probability, relative to 1, of being male (black color), female primiparous (red color) and female multiparous (blue color) with carapace length (in cm). Estimated probabilities by the fit model are depicted by continuous lines while the observed proportions are represented by points.

<u>Diet composition</u>

The estimated diet was also very similar to the observed one, both for cod (Figure 11) and redfish (Figure 12). In both species the model represented important changes over the study period, with variations in the relative importance of all modeled and non-modeled preys. The proportion of shrimp exhibited an increasing trend since 1988 both in cod and redfish diets, that reached the highest values in the late 1990s and stayed at similar proportions until 2004-2005. In these years shrimp was around 25-30% of the diet for immature and mature small cod, 15-20% for mature redfish and large cod and 10% for immature redfish sub-stock. Redfish was a relevant prey all over the study period for both small and large mature cod but it was especially since 2000 when its proportion in the diet increased steadily until maximum values in 2009-2010 (25% in the small and 65% in large mature cod). Cannibalism provided an important percentage to the diet of mature redfish those years when recruitment was high, like in the early 1990s and all over the period 2001-2007 (4.5%). In cod, cannibalism was also important and related to successful recruitments in late 1980s and early 1990s (average 12%) and 2010-2012 (average 7.8%).

The estimated percentage of the non-modeled prey in the diet of both cod and redfish was noteworthy. Hyperiids, euphasiids and chaetognats were very important prey for both predators; while copepods were a main prey only for redfish. The four pelagic groups together accounted for c.a. 50% of diet in immature cod, 75% in immature redfish, and 50% in mature redfish. In small and large mature cod, although it was lower, these prey still contributed to an average 35% and 20% respectively. Wolffishes were a very important prey in the diet of large mature cod, until late 1990s, with an average 32% of the diet. Pelagic fishes (mostly myctofiids) had a prominent role as fish prey in immature, but especially in mature redfish (average 5% and 15% respectively).

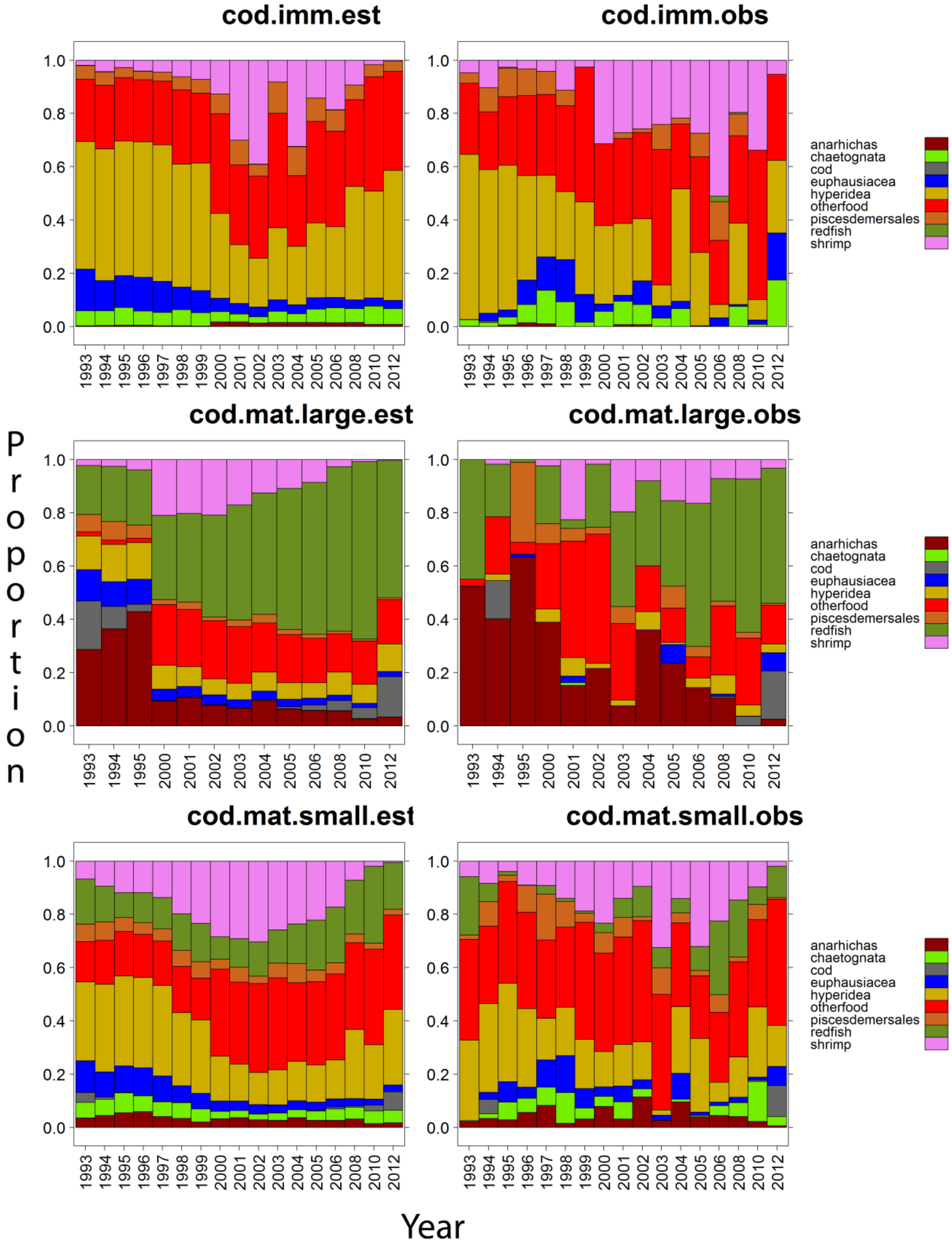


Figure 11.- Estimated (left column) and observed (right column) diet for immature cod (cod.imm), small mature cod (<85cm; cod.mat.small) and large mature cod (>85cm; cod.mat.large).

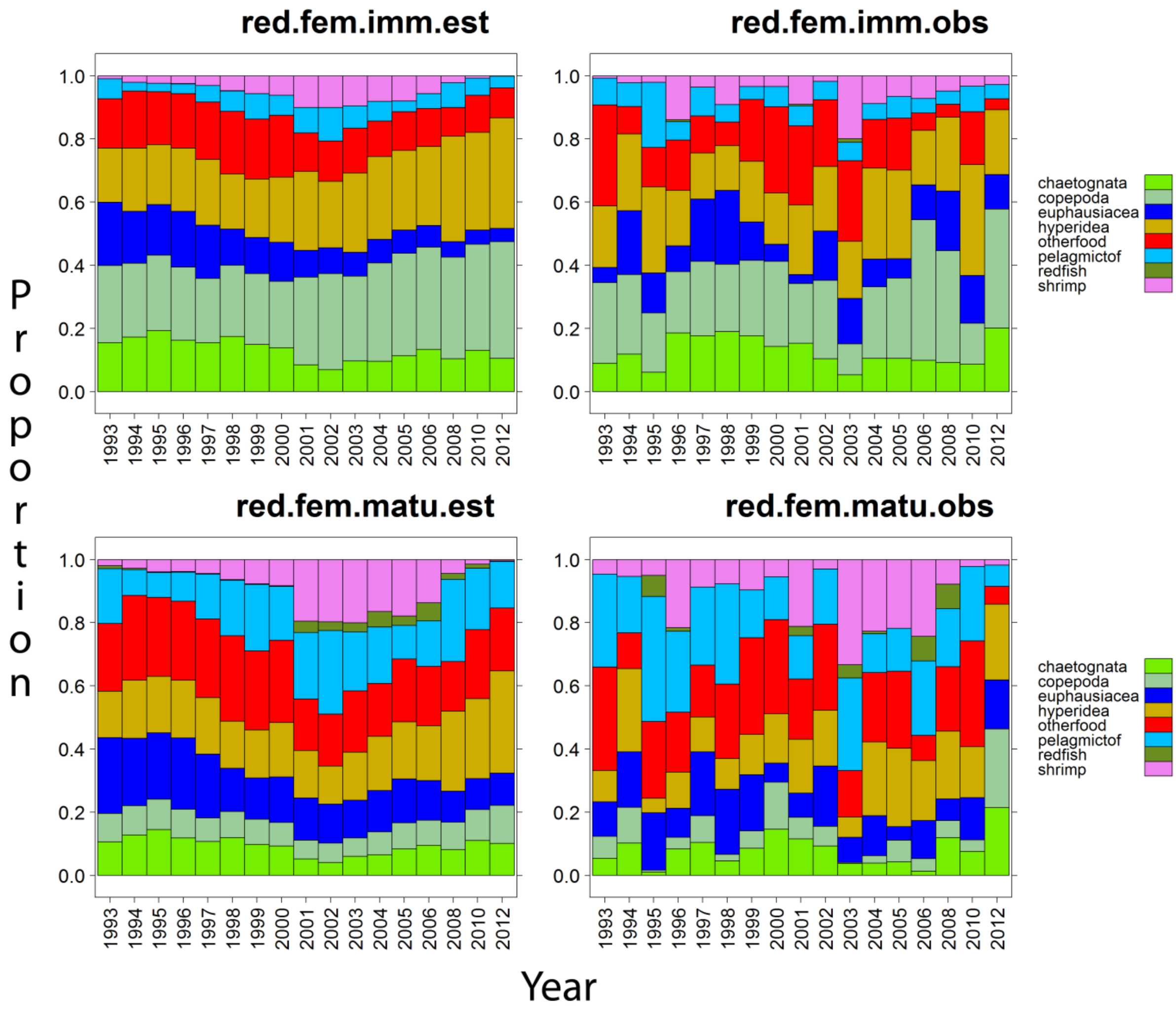


Figure 12.- Estimated (left column) and observed (right column) diet for immature female redfish (red.fem.imm) and mature female redfish (red.fem.matu).

Modeled cod, redfish and shrimp stock dynamic

Model estimates of annual recruitment at age 1, abundance and total stock biomass over the study period were highly variable and showed strong patterns (Figure 13). Cod recruitment was high in years 1991 and 1992, which was reflected in the raise of total stock abundance. However, this increase was followed by a steep decline in years 1993-1995 coupled with the lack of good recruitments. Cod biomass showed a delayed pattern in relation to abundance and stayed at relative high values up to 1995 when it showed a sharp decline until 1998, when the lowest value in the study period was reached. Over the period 1995-2004 estimates of cod recruitment were very low and consequently stock abundance and biomass continued at minimum values over this period. However, in year 2005 recruitment was above the average in previous years and stayed at similar values until 2009, which produced an increase in the abundance. In the period 2010-2012 recruitments were very high, especially in year 2011 when the highest recruitment of the study period was estimated. Total stock abundance reached the highest values since 1988 in these years, while the total biomass reached the highest value in 2012, when the biomass from the mature stock stemming from cohorts 2005-2009 and the immature stock from recent recruitments (2010-2012) added up.

Estimates of recruitment in the redfish stock were very high in the period 1990-1992 (Figure 13). This produced a marked increase in population abundance in 1991 which did not have a reflection in total biomass. On the contrary since 1989 there was a marked reduction in total biomass. After the increase in 1991-1992 the stock abundance showed a sharp decline, reaching the lowest values in the late 1990s. However, over the period 2001-2007 the model estimated a series of excellent annual recruitments, which were especially high in 2001, 2004, 2006 and 2007. These recruitments produced the increase of the stock abundance until 2007, when the highest value was attained. The increase in total stock biomass as result of these successful recruitments became more pronounced since 2003 and reached the highest value in 2009. Since 2007 total abundance declined sharply and was reflected in the reduction of total stock biomass since 2010.

Despite being a burning period that needs to be considered carefully, the model indicates that in 1988-1989 the shrimp stock experienced good recruitments (Figure 13) that produced the increase in the abundance in those years and was the start of a growing trend in the stock biomass. However it was after 1993 when the highest recruitment values were estimated, in a series of successful cohorts that lasted until year 2006. The stock biomass showed a steady increment until the maximum value in 2001 that was followed by a steady and continued decline that was not compensated by the excellent recruitments that kept the abundance at high values until 2004. In 2012 the total biomass reached the lowest value since 1988.

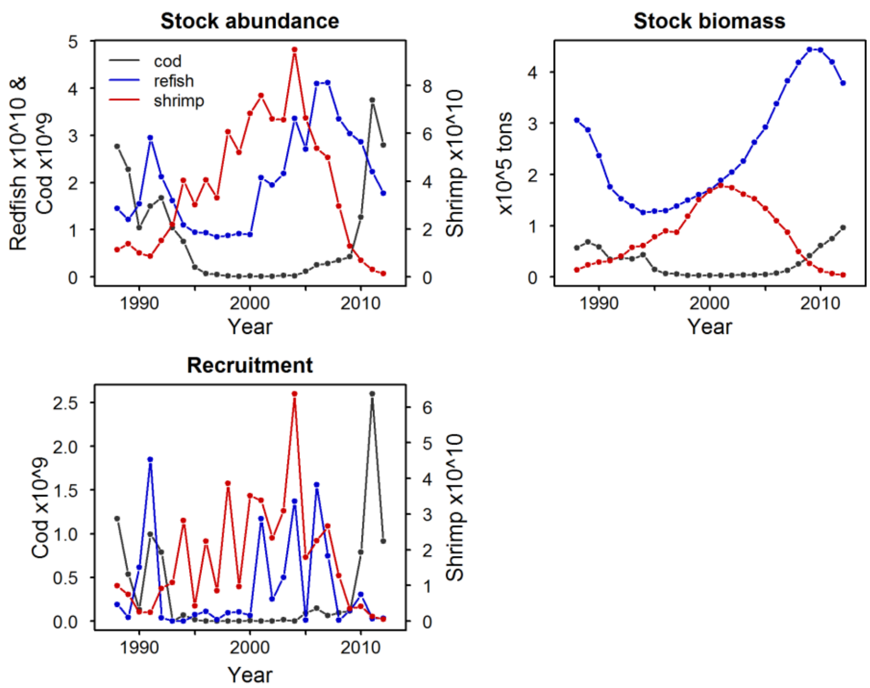


Figure 13.- Model estimates of recruitment at age 1, total stock abundance and biomass for cod, redfish and shrimp along the study period.

<u>Instantaneous and harvest rates by source of mortality</u>

The mortality rates by age due to predation by cod (Mcod) and/or redfish (Mredfish) and fishing (F) were estimated for each modeled stock (Figures 14, 15 and 16). In cod cannibalism was the main source of mortality at age 1 all over the study period (Figure 14), with the highest values in the early and late years. At age 2, cannibalism showed a similar pattern but in this case the highest values occurred in the last years, when the abundance of older and cannibalistic cod was higher. However, since the reopening of the fishery in 2010, both Mcod and F had been similar at this age (close to 0.2). At age 4 and older, cannibalism was negligible and fishing accounted for most of annual mortality, which was extremely high before the collapse (F>1.5 at all ages in 1994). Since the reopening of the fishery in 2010, F at ages 4 and older stayed at relative low values in comparison with the levels of mortality during the 1990s.

In the redfish stock before 1996 the main cause of mortality for individuals younger than age 7 was predation by cod, with Mcod ranging from 0.1 to 0.3 (Figure 15). This range of ages were also affected by the shrimp trawl fishery in the period 1993-1995, with F=0.18 in average, that removed an important portion of the small population. Cannibalism was important in the early 1990s, but it was since 2000 when Mred showed an increasing trend from 0.07 to 0.36 in 2009 at age 1 and values above of 0.1 at age 2. For redfish older than age 9, the redfish trawl fleet was the main cause of mortality during the first part of 1990s, with values above 0.5 at most ages in years 1990-1992. After 1996, fishing mortality by the redfish trawl fleet decreased and stayed at very low levels despite the slight increase observed since 2007. From 2007-2010, Mcod became the most important source of mortality for all ages, with values above 0.2 for ages 2 to 10 and between 0.1 and 0.2 for ages 11 to 18. The exception to this was the age 1 redfish, for which Mred remained as the main cause of mortality.

Other than the residual natural mortality, before the start of the shrimp fishery in 1993 the main source of mortality for shrimp was cod predation (Figure 16), with Mcod above 0.2 for age 1, 0.2 for ages 3-4 and over 0.1 for ages 5 to 7. Since 1990 to 1995 Mcod declined steadily. Since 1993 until 1996 F raised to very high values (higher than 1) for ages 3 to 7. Since 1997 to 2005 F was lower for all ages, but it was still above 0.1 for age 2, 0.3 for age 3 and 0.6-1 for ages 5-7. Since 2006 fishing mortality showed a steady decline until 2011 when, with the moratoria, it became again zero. Since 2000, the estimated Mred showed an increasing trend for all ages, but especially at ages 1-3 (higher than 0.7 in 2008 for age 2 shrimp). Mcod increased steadily since 2005 for all ages and by 2012 was very similar to Mred.

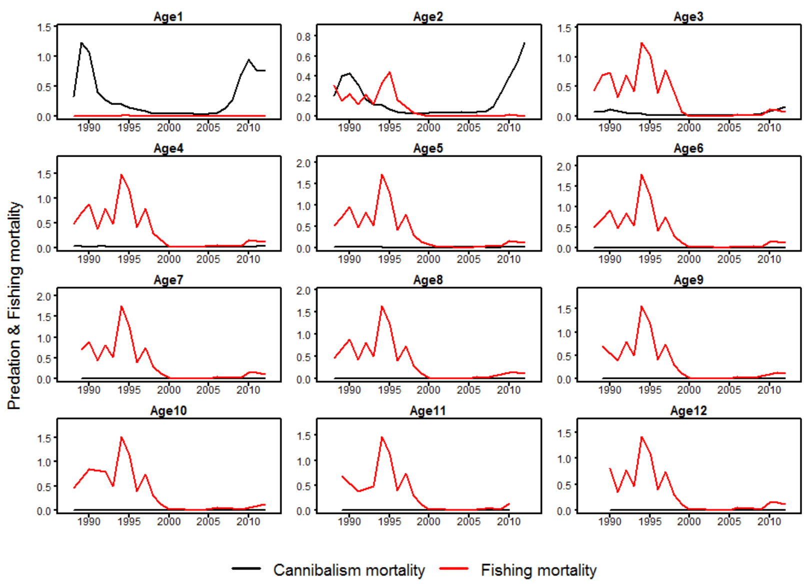


Figure 14.- Predation mortality by cod (Cannibalism mortality) and fishing mortality by age in the modeled cod stock. The Age 12 pannel shows the mortality rates for individuals of age 12 and older.

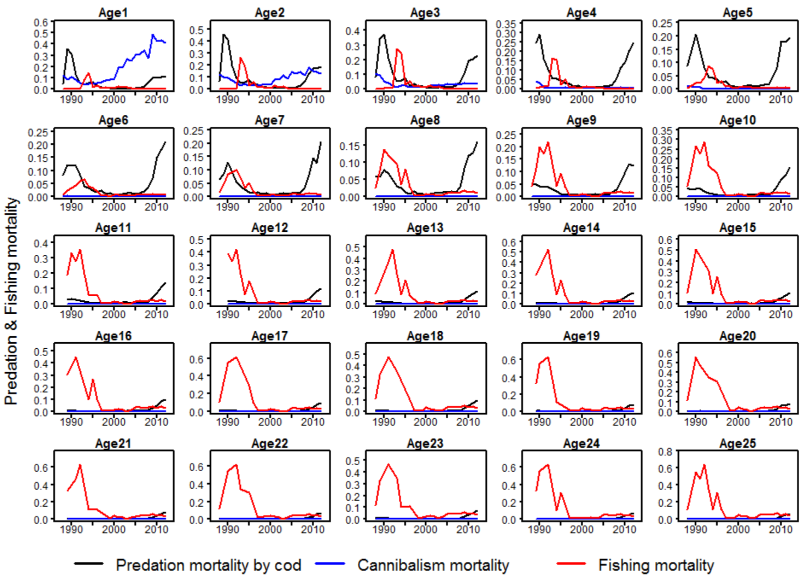


Figure 15.- Predation mortality by age in the modeled redfish stock, by cod, by redfish (cannibalism mortality) and fishing mortality. The Age 25 pannel shows the mortality rates for individuals of age 25 and older.

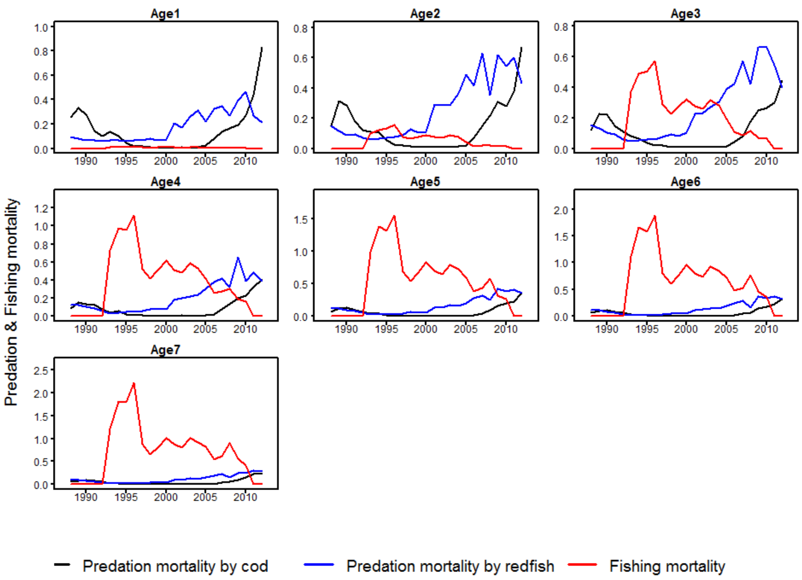


Figure 16.- Predation mortality by cod, by redfish and fishing mortality by the shrimp trawl fleet by age in the modeled shrimp stock. The Age 7 pannel shows the mortality rates for individuals of age 7 and older.

These results allow suggesting that during the recent decline of the shrimp stock, the recovery of the cod stock and the reduction of the redfish stock:

- Since 2005, predation mortality (including cannibalism) has been the main driver in the dynamic of all the three main commercial species in the Flemish Cap.

- In cod, predation (cannibalism) and fishing have occurred mostly at different ages in recent years (excepting age 3), while in redfish and shrimp they have worked simultaneously in a wide range of ages.

- Those years of excellent recruitment, cannibalism has been the main source of mortality both in juvenile cod and redfish, reducing significantly the expectative of increasing stock biomass.

- Predation by redfish, together with fishing have been the main factors driving to the collapse the shrimp stock. Predation by cod contributed to the decline of shrimp especially after 2007-2008.

- The increment of large cod in the stock, especially since 2010, has raised the predation mortality on redfish, and is the main factor inducing the decline of abundance and biomass in the last years.

Comparison with the Single species stock assessment models:

Cod

Trends in the estimates of total population biomass were very similar to the estimated by the current Bayesian XSA single species stock assessment model (Figure 17) (González-Troncoso 2015). However the multispecies model produced higher values of biomass in the last years, which was due to differences in the estimated Spawning Stock Biomass (SSB). These differences in the total SSB could be partially explained by the higher estimates on recruitment in years 2005 and 2006, as well as by the difference in the age of the plus group. While in the multispecies model the plus group is set at age 12, in the single species model this group is defined at age 8. This difference could lead to a higher biomass in the SSB of the multispecies model in the last years, especially after a long period without fishing activity that would allow in the model a high proportion of survivors for those cohorts after 1996. Estimates of recruitment at age 1 were also higher in the multispecies model since 2010, but also was higher already in 2005 and 2006 which, as will be commented later on when the predation mortality is presented, could be due to cannibalism, not considered in the single species model. All these questions will need further research in the future.

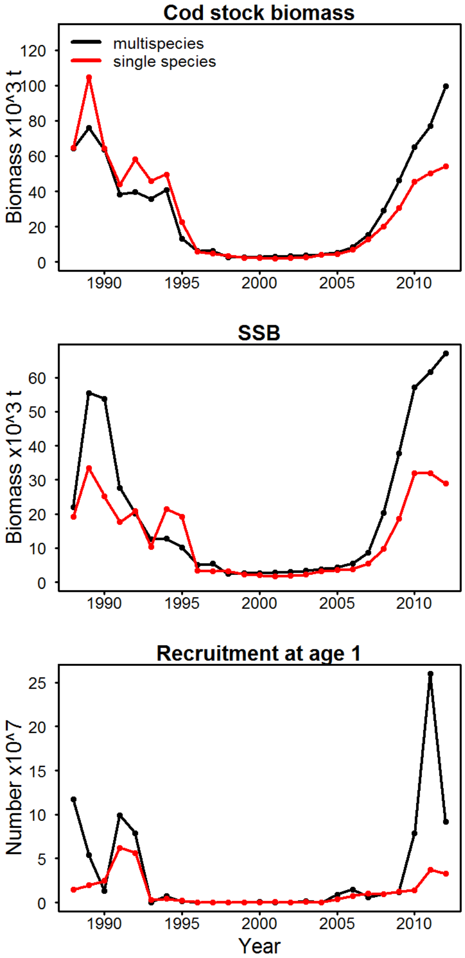


Figure 17.- Comparison of the estimated total cod stock biomass, SSB and recruitment at age 1 by the multispecies (black dotted lines) and the bayesian XSA single species model (red dotted lines).

Redfish

The estimated total stock biomass for individuals older than age 4 (Figure 18) showed very important differences in relation to the estimates from the single species stock assessment model (Ávila de Melo et al. 2013). This differences, in addition to the fact that they by esence two different model approaches, may be related with different factors: 1) the fact that in the single species stock assessment only the beaked redfish species (Sebastes mentella and S. fasciatus) are included, while in the multispecies model, in addition to these species S. marinus was also considered. 2) Despite the single species stock assessment tried to include in 2013 part of the mortality due to predation (Ávila de Melo et al. 2013), it is not comparable to the modelling of natural mortality by predation considered by the multispecies model, which would lead to higher estimates of biomass. In addition to the potential differences induced by these two factors, despite the important by-catch from the shrimp fishery in these years survivorship of cohorts 1990-1991 is high in the multispecies model, in comparison with the low survivorship of this cohorts estimated in the single species model (Ávila de Melo et al. 2013). In relation to this, during the meeting in Halifax some of the members of the WGESA suggested including somehow the increase in natural mortality that the rise in biomass of Greenland halibut and Wolfish species (which also preyed on redfish in these years) might have induced. This, in addition to other factors as migrations, changes in natural mortality and catchability, as well as the difference due to a different plus group in both models (19+ in the single species model in comparison to the 25+ group in the multispecies model) will be explored in the future.

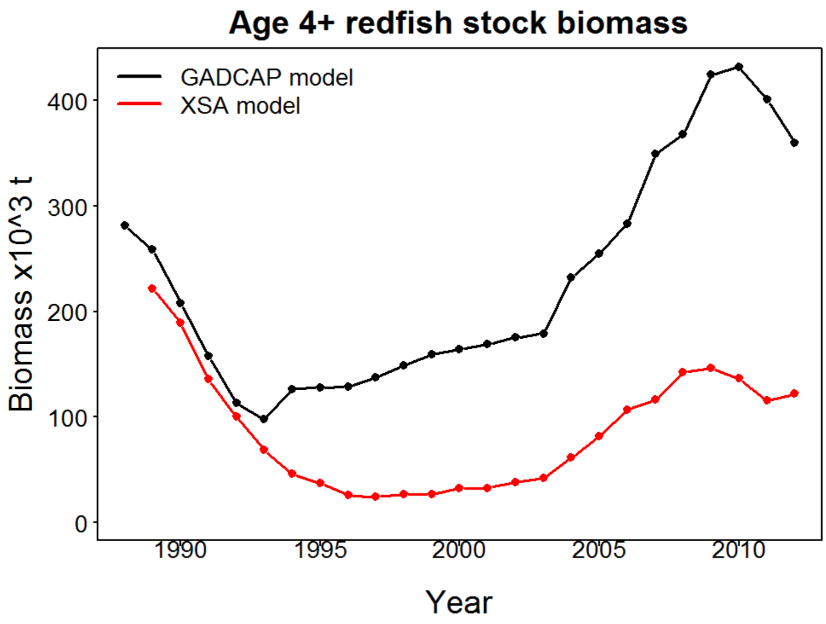


Figure 18.- Estimated total stock biomass by the multispecies (black dotted line) and the XSA single species stock assessment model (red dotted line) (Ávila de Melo et al. 2013) of individuals older than age 4.

<u>Multispecies Maximum Sustainable Yield (MSY) estimates</u>

In order to show the potential of this gadget multispecies model for the estimation of joint MSY for cod, redfish and shrimp a preliminary exercise was conducted. The fit model was employed to perform long term simulations, where:

- Simulation was run for the period 2013-2200
- Length-weight relationship, growth, consumption, and several other life-history related parameters were averaged to the period 2007-2012
- Ricker stock recruitment relationship fit to the model estimates of recruitment and SSB.
- 10 different levels of fishing mortality for each species: 1000 combinations (1000 different runs).
- For each of these 1000 runs estimate stock biomass, SSB, catches and recruitment for each species.
- Explore Stock biomass and MSY estimates using boxplots, categorized by fishing mortality for each species.

Figures 19 and 20 showed estimations for total stock biomass and MSY respectively. The boxplots depict the 25 and 75 percentiles in the lower and upper box limits, and the median in the black centered line. Despite the model is still in an early stage of development the overall values of biomass and MSY estimated for each species in relation to changes in fishing mortality in the other species were in sensible orders of magnitude. In addition it showed interesting patterns result of the negative effect of fishing mortality in prey or predator stocks. On this regard, it is interesting to note that the expected patterns of decrease in biomass as result of increasing fishing pressure were observed in all the three stocks. But other than this trivial fishing-stock reaction, more interesting secondary reactions were observed like the negative effect of higher fishing mortality on redfish or shrimp in total production and MSY for cod. The effect of prey abundance on predator growth has not been model at this stage, and this negative impact was the result of the increased cannibalism that the reduction in main prey as redfish and shrimp produced in cod stock. It is also interesting the positive effect in redfish biomass and MSY produced by increasing cod fishing mortality. The same is observed in shrimp biomass and MSY in relation to redfish and cod fishing pressure.

During the WGESA meeting in Halifax it was concluded that the estimated stock biomass and MSY values is not yet ready to be taken for management decision at this stage, since the SSB-Recruitment relationships and the multispecies model that produce these estimations still need further work, improvements and checkings. However, it was recognized the usefulness for future management of this multispecies model for the Flemish Cap, which is already producing estimates and simulations of population dynamic that are in reliable orders of magnitude. The model also reproduces with high fidelity the trophic interactions among species, and can already estimate predation mortality by age, and perform long term simulations to explore different fishing and environmental scenarios. These are two very useful outputs that in the future could be considered for stock assessment and management decisions in NAFO.

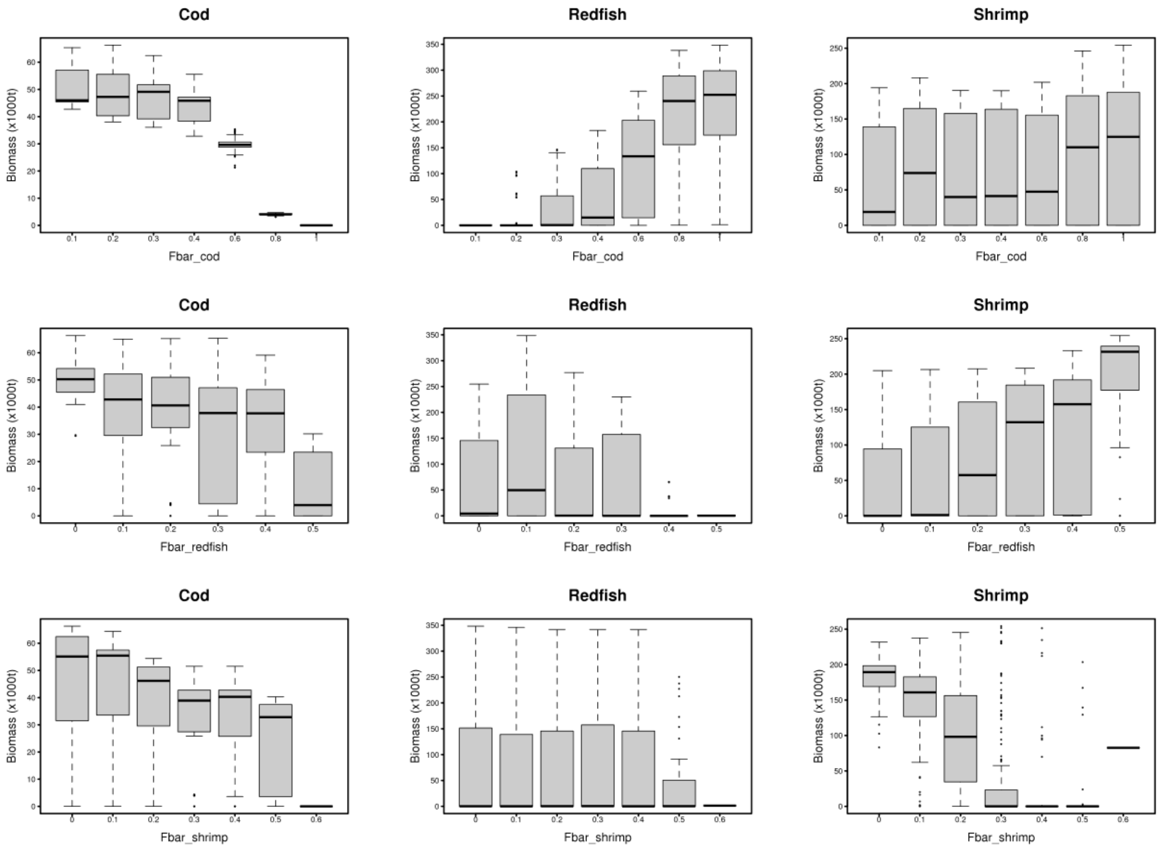


Figure 19.- Estimated stock biomass by species (defined by column) under varying fishing mortality for another species (defined by row). The boxplots contain the variability of estimated stock biomass for all the possible combinations of fishing mortality for the other two species. Thus, the right column depicts the biomass of shrimp on the y-axis under different target fishing mortalities on cod (top), redfish (middle) and shrimp (bottom) on the x-axis.

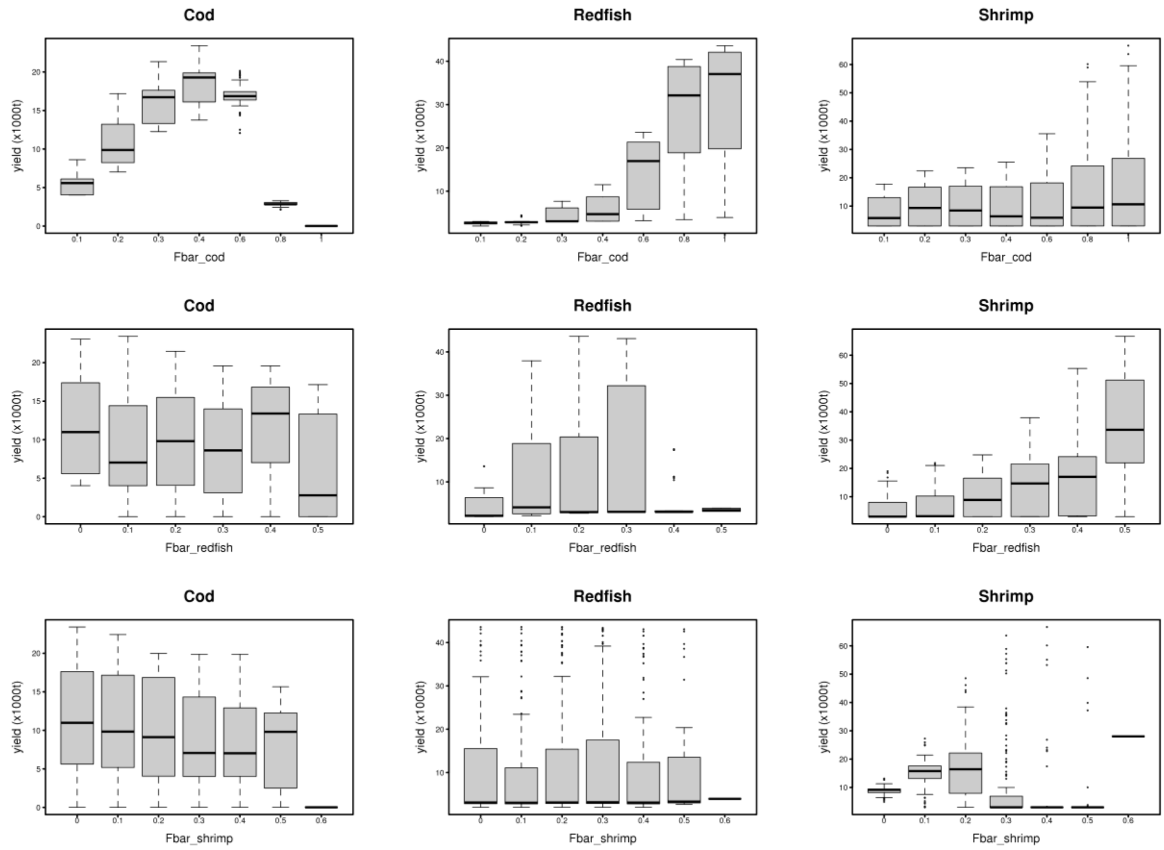


Figure 20.- Estimated MSY by species (defined by column) under varying fishing mortality for another species (defined by row). The boxplots contain the variability of estimated MSY for all the possible combinations of fishing mortality for the other two species. Thus, the right column depicts the MSY of shrimp on the y-axis under different target fishing mortalities on cod (top), redfish (middle) and shrimp (bottom) on the x-axis.

4.- Potential impact:

Potential impact and exploitation of results

The first goal of project GadCap was to develop a multispecies model and a framework to perform long term forecast simulations that allow quantify natural mortality due to predation and could be used to estimate biological and fishing parameters associated with the Maximum Sustainable Yield from a multispecies perspective (Spawning Stock Biomass and Fishing mortality at MSY (SSB_{msy} or B_{msy} and F_{msy}). The second goal was presenting the project and the results to the fisheries scientist community in general, but specially to the NAFO Scientific Council NAFO-SC and the Working Group for the Ecosystem Studies an Assessment NAFO-WGESA. The aims of attending to the annual meetings of these scientific bodies were on the one hand receiving feedback that could serve to improve the structure and performance of the multispecies model. On the other hand the goal was incorporating the results of this project to the roadmap of the WGESA and provide the NAFO-SC with a tool that could be used to improve the stock assessment by using the estimates of predation mortality as support in the stock assessment and management of the main commercial species of Flemish Cap: cod, redfish and shrimp. In addition there was a third goal, regarding with the development of a innovative research project in the NAFO area, that launch the development of multispecies models and promote the development of the ecosystem approach to fisheries management.

These goals have been fulfilled, the multispecies model has been developed and parameters related with the interactions between all the three commercial stocks and fishing has been evaluated, and multispecies B_{msy} and F_{msy} have been estimated. Results have shown that natural mortality values are higher than usually assumed by the single species models, that they change with age for all the three stocks, and vary over time. The multispecies model is able to disentangle the interconnected drivers of the abundance of the cod, redfish and shrimp stocks in the Flemish Cap. Since 1988 to 2012 overfishing, predation and cannibalism, and variable recruitment success have combined to produce strong swings in the biomass of all three stocks. The model has shown that predation was the explanation to most of the changes observed since 2005 in the three main commercial species in the Flemish Cap. In shrimp, both predation by redfish and fishing worked together driving the collapse of the shrimp stock, with the final contribution of predation by cod. The portion of large cod in the stock, especially since 2010, raised the predation mortality on redfish and seems to be the main factor inducing the decline of abundance and biomass since 2010 and still continues nowadays. The model has also described that during those years of high recruitment cannibalism has been the main source of mortality both in juvenile cod and redfish, and has reduced significantly the expectative of increasing the biomass of the stock. In this regard, predation (including cannibalism) and fishing is co-occurring nowadays at age 3 in cod and most ages in redfish and shrimp. Additionally, the model has revealed the relevance of external prey groups like hyperiids and eupaussids for immature, small mature cod and redfish, the genus Anarhichas sp for large mature cod, and copepods for redfish. These results suggest that the potential decline of some of these alternative prey groups may have important consequences in the dynamic of the commercial species by changing predatory (and cannibalism) interactions. This last goal goes beyond of the multispecies approach and enters into the ecosystem approach.

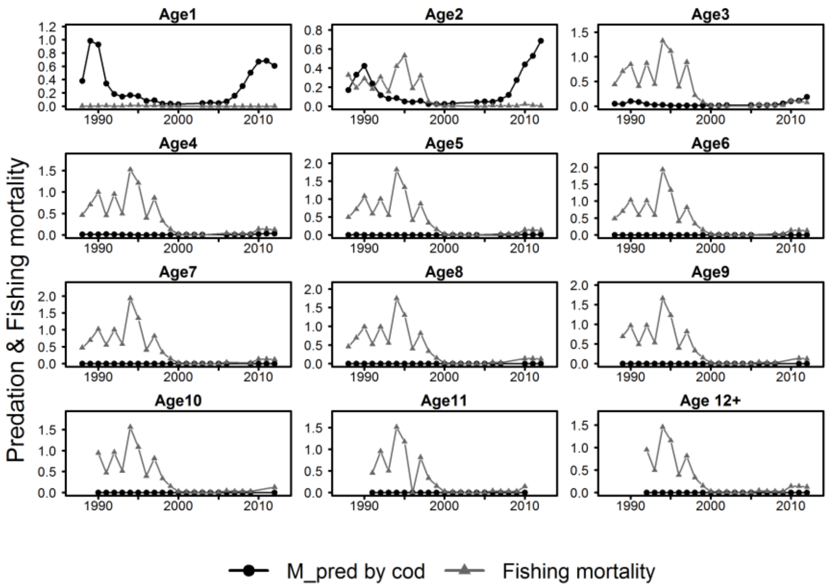


Figure 1.- Predation mortality by cod (M_pred by cod) and fishing mortality by age in the modeled cod stock. The “Age 12+” pannel shows the mortality rates for individuals of age 12 and older.

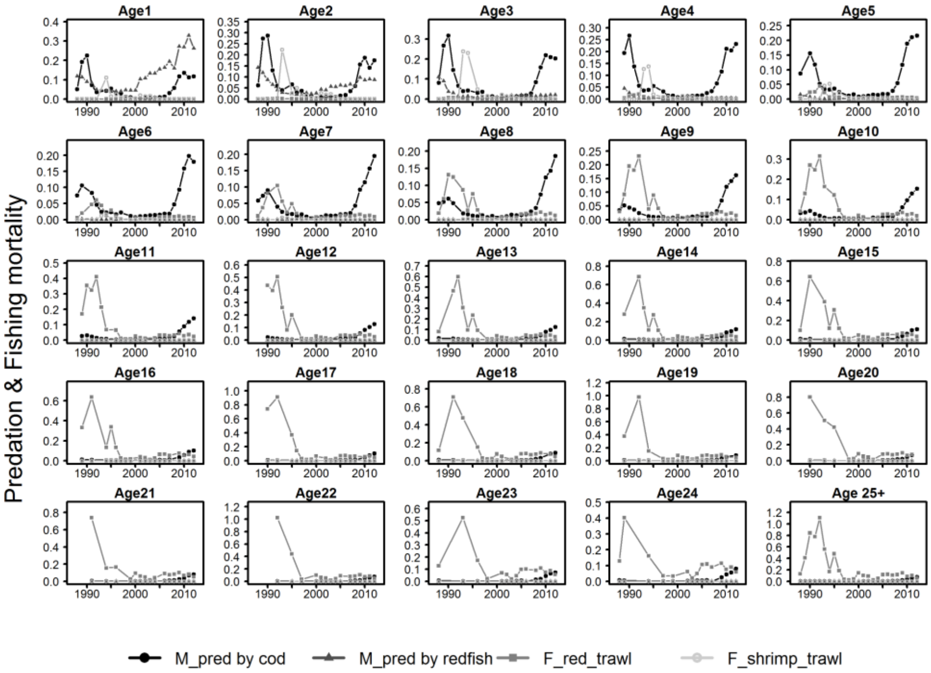


Figure 2.- Predation mortality by age in the modeled redfish stock, by cod (M_pred by cod), by redfish (M_pred by redfish) and fishing mortality by the redfish trawl fleet (F_red_trawl) and the shrimp trawl fishery (F_shrimp_trawl). The "Age 25+" pannel shows the mortality rates for individuals of age 25 and older.

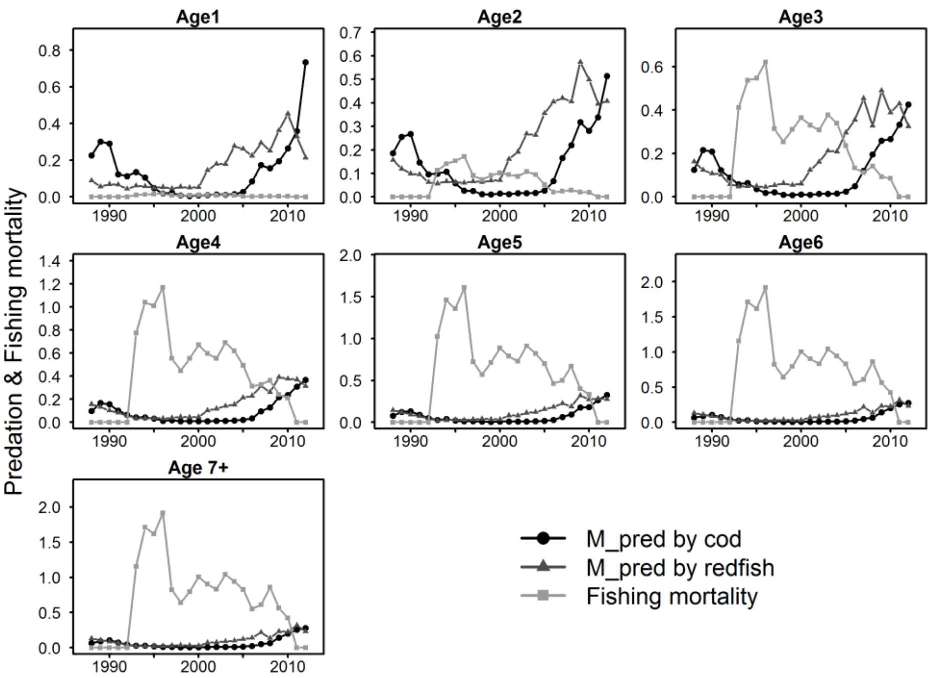


Figure 3.- Predation mortality by cod (M_pred by cod), by redfish (M_pred by redfish) and fishing mortality by the shrimp trawl fleet by age in the modeled shrimp stock.

Therefore, the results of this project clearly indicate that disregarding the species interactions in the assessment of the Flemish Cap cod, redfish and shrimp would lead to serious underestimates of both the magnitude and the variability of natural mortality and this was demonstrated to the WGESA members. This would involve an overestimation of the exploitable biomass in the short-term projections supporting management decisions, both by an excessive positivism in relation to the future survival of successful recruitments and the overestimation of survivorship for the fishable part of the stock. It has also been shown that due to the prey-predator size relationship and the dynamic of prey-predator stock populations induced by variable recruitment, trophic interactions have a high degree of plasticity and are beyond of being only species interactions but size-modulated specific interactions. This should be seriously considered when evaluating the effect of a predator on a prey stock, otherwise the assessment of predation mortality could be misleading. Accordingly, the multispecies model developed in this work presents a very suitable tool not just to understand the importance of predation, fishing and recruitment as drivers in the dynamic of the Flemish Cap system but also to quantify the shape and magnitude of species interactions as well as synergies among drivers, which could be used to support the stock assessment in the Flemish Cap.

These results were presented to the WGESA during the November 2015 meeting in Halifax. A full presentation of the model structure and upto date results was carried out. It was recognized by the scientific group the great advancements achieved in two years and the large amount of interesting results of usefulness for the NAFO stock assessment and management bodies. It was stated that the population abundance and biomass estimates from this model were very similar to those resulting from the Ecosystem and Fisheries Production Potential models estimates and the single species models, and some ideas were provided to improve the model performance. Differences were related with the different assumptions and processes modeled by each approach. Comments and feedbacks from the WGESA scientists during the November 2015 meeting were very positive, and it was highlighted as a very useful tool already now, but that it has a great potential in the future by itself, but specially due to the great possibilities that it offers as a simulation tool to be utilized in several different projects related with climate change, and management strategy evaluation. It is expected then that once these results are presented also to the SC of NAFO during the June meeting in 2016 (the chair of the WGESA will do it), this information will have an impact in the natural mortality considered in the single species stock assessment model, and, as explained above, will suppose a first case study that will show to several members of this SC the potential and usefulness of these multispecies models for stock assessment and management decisions.

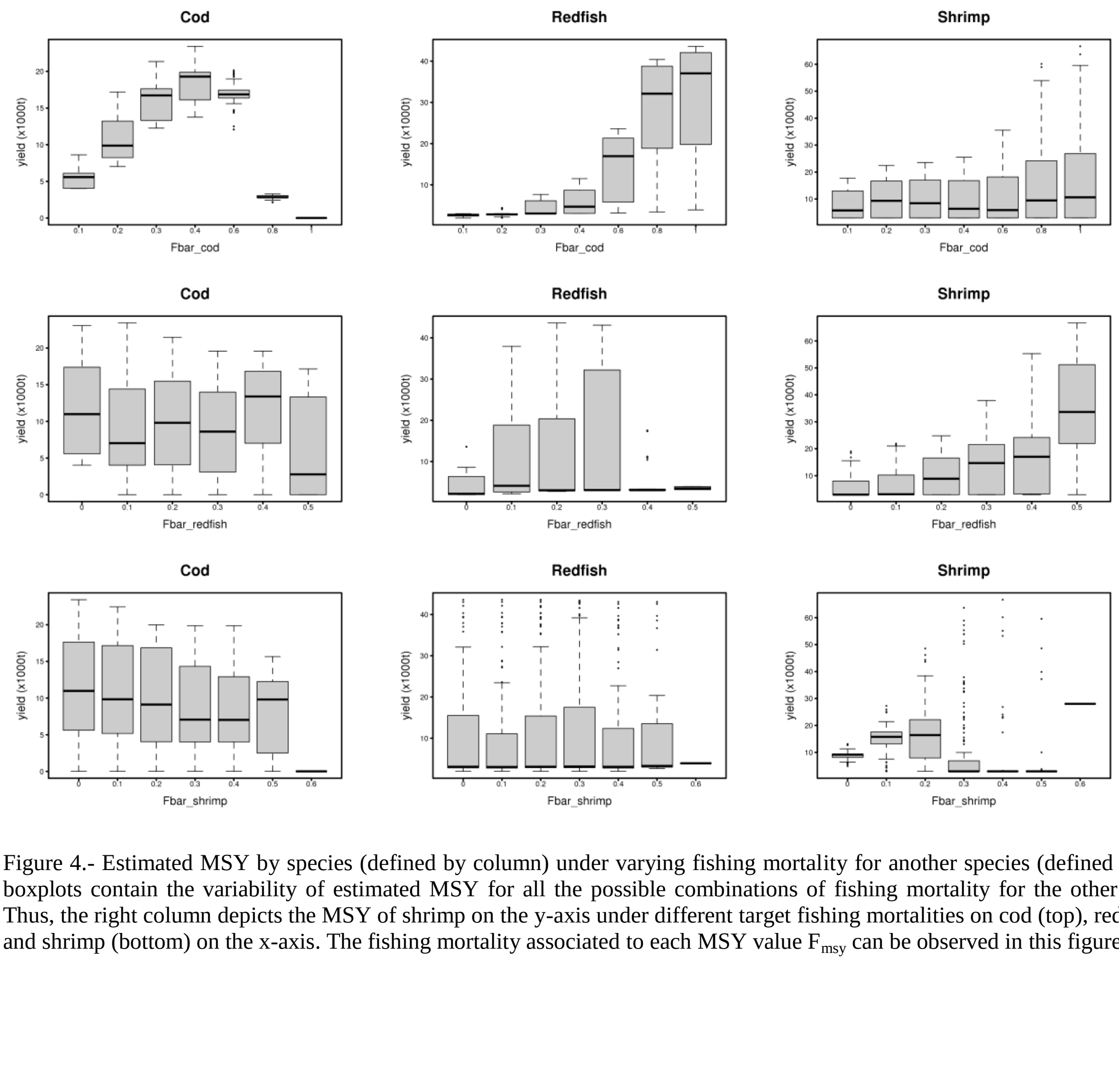


Figure 4.- Estimated MSY by species (defined by column) under varying fishing mortality for another species (defined by row). The boxplots contain the variability of estimated MSY for all the possible combinations of fishing mortality for the other two species. Thus, the right column depicts the MSY of shrimp on the y-axis under different target fishing mortalities on cod (top), redfish (middle) and shrimp (bottom) on the x-axis. The fishing mortality associated to each MSY value F_{msy} can be observed in this figure.

One very important impact in the NAFO scientific community is that it will promote a new way of thinking in relation to the assessment and advice in fisheries management, more in line with the roadmap for the EAF in NAFO, where the multispecies models like the one develop as part of GadCap are key elements (Figure 1).

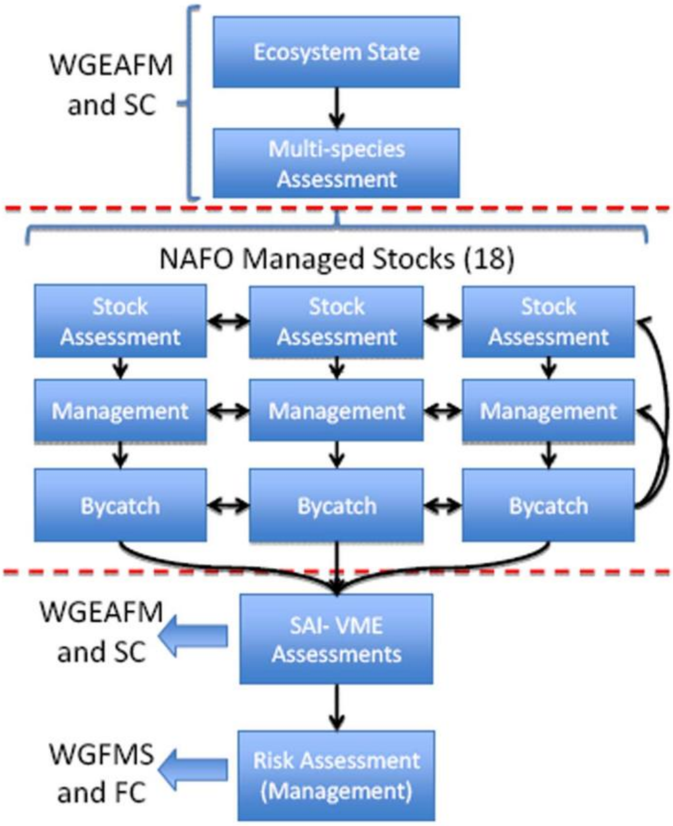


Figure 5.- Schematic representation of a possible structure to develop Fisheries Assessments in NAFO proposed by the WGESA in its 4th meeting, 2011

Dissemination activities

Dissemination activities have been developed both at the general public and scientific levels. In relation to the general public, the website for the project GadCap was developed (https://gadcap.wordpress.com/) and the project was presented in the public media through the newspapers and interviews in the Spanish and Galician broadcast (see some examples in https://gadcap.wordpress.com/spreading-gadcap/). During the second stay in Vigo (Spain) in September 2014, an interview in the Galician television program “Vivir o mar” (living the sea) was given, introducing the project GadCap and the multispecies approach to fisheries management.

In relation to the scientific community the project GadCap was presented to specialists from ICES and NAFO working groups and scientific councils, both as a spreading activity in the fisheries scientific community and as a way of receiving feedback from specialists in the matter. The last week of September 2014, Alfonso Pérez attended to the 36th NAFO (Northwest Atlantic Fisheries

Organization) annual meeting, held in Vigo. The GadCap project was presented to the NAFO scientific council, their goals, the expected results, as well as the potential relevance of this project for NAFO management approach. It was the first time that this EU Marie Curie project was presented to the scientific community for which it had been devised. From 20th to 24th of October GadCap was presented in the meeting of the Working Group on Multispecies Assessment Methods WGSAM of ICES, in London. This was an outstanding opportunity to met and learn from some of the best scientists related with the multispecies stock assessment modelling. Finally, from 17th to 28th of November the project was presented during the meeting of the NAFO Working Group on Ecosystem Studies and Assessment WGESA. The GadCap project was presented, and the Gadget modelling framework was tackled in depth, since this is the working group where it is expected that the results from GadCap will be more directly useful and applicable.

Over 2015, during the first stay on January 2015 at the IEO in Vigo (Spain), a seminar was presented in the Campus of the Sea, which belongs to the University of Vigo. In this speech a review was presented to marine biology students in relation to the evolution of stock assessment models and procedures in fisheries management, with special attention to the last approaches. The EU Marie Curie project GadCap was presented as an example of the works being develop nowadays on the multispecies modeling approach. Link to the video website: http://tv.uvigo.es/video/111946.html

The second stay in the IIM, IEO and IPMA occurred in early September. A special meeting was held, with all scientists that had contributed in this project. The goal was presenting the up to date results of the multispecies model in order to get their view of the level of performing of the model and discuss the results that would be presented later on in the ICES Conference of Copenhagen from 21st to 24th September. In this congress the results of the project GadCap were presented to the scientific community as an oral presentation in the Theme Session A, “Advancement of stock assessment methods for sustainable fisheries”.

Finally, the cod, redfish and shrimp multispecies model, as well as the estimation of multispecies fishing mortality, spawning stock biomass and total biomass at MSY were presented to the scientific community in the ICES WGSAM meeting in Woods Hole (Massachusets, USA) from 9th to 13th November and the NAFO WGESA from 17th to 26th of November in Halifax (Canada). During the ICES WGSAM meeting it was especially important the conversations with Morten Vinther, from the National Institute of Aquatic Resources (DTU Aqua) of Denmark. Dr. Vinther is currently one of the most advanced scientists in multispecies modeling. He has developed the Stochastic Multispecies model SMS that is used nowadays in the scientific advice for management in the North Sea. During the WGSAM meeting he provided some very useful ideas about the ways to extract to the Flemish Cap multispecies model the potential for advisement in a multispecies fisheries context. Finally, as explained in the previous section, the NAFO WGESA in Halifax (Canada) could be considered the most important scientific meeting of GadCap, since all the work develop during the two years of GadCap was made to be integrated into this working group and the NAFO scientific council. During the days of the meeting the structure of the model, the databases employed, the diagnostics, as well as the population estimates and long term forecasts on MSY were presented.

4.2 Use and dissemination of foreground

Section A (public)

A project of applied ecology research as it is GadCap has interest to the scientific community from two different perspectives, and as accordingly needs to be disseminated in two different ways. One of this perspectives is more related with ecology knowledge and understanding. The other one is the more purely applied perspective. For this reason results need disseminated in two different ways. One of them is through the publication of results in peer reviewed journals, were the most outstanding results, of interest for a broad part of marine ecologist is interested. The other one is of interest almost exclusively to the more close scientific community, directly related with the field and or organization were the results will be applied. In this second case it is not just of interest the results and conclusions, but the methodology itself needs to be very well explained.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Dynamic of the Flemish Cap commercial stocks: use of a gadget multispecies model to determine the relevance and synergies between predation, recruitment and fishing*	*Pérez-Rodríguez, A.*	*Canadian Journal of Fisheries and Aquatic Sciences*	*Annual*			*In press*			No
2	GadCap: A Gadget multispecies stock assessment model for the Flemish Cap	Pérez-Rodríguez, A.	NAFO Scientific Council	*Annual*			*In press*			Yes

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

			Research Document							
3										

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience[4]	Size of audience	Countries addressed
1	Interview in Journal	Pérez-Rodríguez,A	Faro de Vigo	January 2014	Vigo (Spain)	Public		Spain
2	Website	Pérez-Rodríguez,A	GadCap	January 2014	https://gadcap.wordpress.com/	Public		International
3	Interview in radio	Pérez-Rodríguez,A	Español es en el mar	Febrero 2014	http://www.rtve.es/alacarta/audios/espanoles-en-la-mar/espanoles-mar-trabajo-mujer-mar-27-02-14/2421314/#aHR0cDovL3d3dy5ydHZlLmVzL2FsYWNhcnRhL2ludGVybm8vY29udGVudHRhYmxlLnNodG1sP3BicT02Jm9yZGVyQ3JpdGVyaWE9REVTQyZtb2RsPVRPQyZsb2NhbGU9ZXMmcGFnZVNpemU9MTUmY3R4PTE5NzQmYWR2U2VhcmNoT3Blbj1mYWxzZQ==	Public		Latin countries
4	Interview in television	Pérez-Rodríguez,A	Vivir el Mar	September 2014	Vigo (Spain)	Public		Spain

[4] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

5	Presentation	Pérez-Rodríguez, A.	ICES-WGSAM 2014	20th-24th October 2014	London (UK)	Scientists	20	International
6	Presentation	Pérez-Rodríguez, A.	NAFO-Scientific Council	22nd-26th September 2014	Vigo (Spain)	Scientists	50	International
7	Presentation	Pérez-Rodríguez, A.	NAFO-WGESA 2015	18th-28th November 2014	Halifax (Canada)	Scientists	30	International
8	Presentation	Pérez-Rodríguez, A.	Conferences of the Campus do Mar	15th January 2015	http://tv.uvigo.es/video/111946.html	Students/Public	20	Spain
9	Conference	Pérez-Rodríguez, A.	ICES Annual Science Conference	21-25 September 2015	Copenhagen	Scientists	100	International
10	Presentation	Pérez-Rodríguez, A.	ICES-WGSAM 2015	9th-13rd November 2015	Woods Hole (USA)	Scientists	40	International
11	Presentation	Pérez-Rodríguez, A.	NAFO-WGESA 2015	17th-27th November 2015	Halifax (Canada)	Scientists	30	International

Section B (Confidential[5] or public: confidential information to be marked clearly)

Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[6]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

[5] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[6] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Multispecies model	Gadget multispecies model for the Flemish Cap, including cod, redfish and shrimp	*NO*		Multispecies model prepared to be used as basic tool in future assessment and management projects	Northwest Atlantic Fisheries Organization and European Union fisheries bodies			
Estimates of predation mortality	Estimates of predation mortality induced by each predator by age and size of prey population.	*NO*		Use of estimated natural mortality due to predation in the single stock assessment models used nowadays for scientific	Northwest Atlantic Fisheries Organization and European Union fisheries bodies			

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[8] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
				advise				
Long Term Forecast Framework	Model structured to produce simulations over long time periods with stock-recruitment relationship	*NO*		Simulate the consequences of various fishing and environmental scenarios. Support to management decisions	Northwest Atlantic Fisheries Organization and European Union fisheries bodies			
MSY, F_{msy}, B_{msy} and SSB_{msy}	Estimates of Multispecies Biological and Fisheries MSY associated parameters	*NO*		Additional input to be considered when setting the HCRs for the exploited cod, redfish and shrimp stocks.	Northwest Atlantic Fisheries Organization and European Union fisheries bodies			

Multispecies model:

The multispecies model develop in GadCap is the most important output obtained. With some additional work it has been made possible the next three exploitable foregrounds. But this is only the beginning. The model still could be improved in the future, but as it is right now it can be already used for several different purposes. New projects are already envisioned and have already been applied for funding to different institutions, as independent projects (Spanish Ministry of Industry and Economy) or as part of a much larger framework (Horizon 2020). In this projects an innovative approach to the risk assessment of different management procedures is proposed. It is a multispecies management strategy evaluation tool, that would have this multispecies model at the very core of the framework, as an operative model. This is a completely innovative approach, that will suppose an outstanding step forward the ecosystem approach to fisheries management.

Hence, the current applicability of the multispecies model would be the three exploitable foregrounds that are described below, however, this is only the beginning, and it is expected that in the next months this multispecies model will be the basis supporting new applied research to improve the assessment of stock status and management procedures associated risk. However, in addition to these utilities, the multispecies can be used today to understand the ecological functioning of the exploited ecosystem, which is a very broad benefit, by allowing to explore several different questions related with environmental and fishing interactions.

This multispecies model has been develop in the Flemish Cap due to the ideal conditions in relation to data availability and ecological features. However this has always been considered as a case-study. Hence, although the results of this project are now available to be used by the scientist of the Working Group for Ecosystem Studies and Assessment of NAFO (WGESA), in support of the Scientific Council SC, or directly the SC itself to advice the Fisheries Commission for management decisions in the Flemish Cap, this project is expected to serve as an example that will be applied to other areas in the NAFO area in the near future.

Estimates of Predation mortality

The first currently exploitable output from GadCap is the capacity of estimating predation mortality. In combination with the forecast framework, populations can be projected into the future in short term forecast (3-4 years) and can be used to estimate natural mortality values due to predation. This information is not currently available and then, single species models assume constant values of natural mortality based in strong assumptions that are very probably far from reality. This model has shown that assumed natural mortality values are probably lower than real values, which would entail a very optimistic forecast of future fishable biomass available for the industry, and eventually to continuous corrections of long term management plans.

As indicated above, still several improvements can be done to the multispecies model but it is already prepared to be employed to calculate predation mortality values which can be already applied in the single species stock assessment and will suppose an improvement in the reliability and stability of management plans.

As all the outputs of GadCap project this information is available to be used by the scientists of the Working Group for Ecosystem Studies and Assessment of NAFO (WGESA), in support of the Scientific Council SC, or directly the SC itself to advice the Fisheries Commission. As one of the main contracting parties of NAFO, the EU is one of the most important users of these results.

Long term forecast framework

The multispecies model is the basic and most important output of GadCap. It can be used to reconstruct the past and understand the changes and causalities related with the modelled processes. This is of great usefulness since it provides a highly valuable knowledge that could be used in a qualitative way for management, since understanding the past can help to manage the future. However, concrete management measures need from quantitative approaches, and this is what has been dealt with the long term forecast framework. This framework has projected the modelled populations into the future by connecting the estimated reproductive stock with an expected recruitment success in the future. In addition this framework includes the possibility of setting Harvest Control Rules that modulate the fishing activity in relation to some biological reference points. There exist many other features of the multispecies model that can be defined, like the availability of alternative food or the effect of water temperature.

This framework can be employed to explore the consequences of applying different management procedures to each of the modelled stocks (cod, redfish and shrimp). But it can also be utilized to simulate different situations in which prey-predator interactions vary over time, or the effect of water temperature produces changes in consumption rates. Many other features of the model could be changed and explore consequences in the short and long term. But, the most relevant feature in relation to management is probably related with the fishing activity, the effort and the suitability functions, and this is already available to be explored by the NAFO-SC in its advice to the Fisheries Commission for management decisions.

MSY and associated parameters:

NAFO in its area of influence set the HCRs based in the Precautionary approach framework. This approach relies in biological and fisheries reference points against which the current state of the populations and levels of fishing pressure are compared. This information in a framework of well define Harvest Control Rules allow the decision-making process with high level of objectivity. Some of these reference points are based in the concept of MSY, which is widely interpreted as the maximum long term average catch that can be achieved under prevailing conditions (including both the state of the ecosystem and size selectivity of the fishery). MSY is considered to be achieved by a fishing mortality (F_{msy}) that produces a high long term average yield while the stock biomass fluctuates around a value where production is at or close to the maximum (B_{msy}). However, this is done with single species models, were once the model parameters are defined, the only factor inducing variability is fishing. However, ecosystem does not work in this way and changes in a prey population can induce variations in predator and in alternative prey populations, and this is what the multispecies model develop in GadCap supposes an improvement. The multispecies model in conjunction with the long term forecast framework can be used to estimate the maximum sustainable yield (MSY) from a multispecies perspective (msMSY).

The long term forecast framework make possible estimating the MSY and Fmsy and Bmsy associated parameters for each commercial species as results not only of varying fishing mortality level in a particular stock but in all the stocks at once. In this way by changing the fishing mortality in cod one could expect that MSY and Fmsy and Bmsy associated parameters for its prey species redfish and shrimp will change. This framework, although still will have to be taken with caution and many different sections of the framework can be improved, it is already available to be used by the NAFO-SC and considered as part of the decision-making process.

The impact of this approach is the possibility of introducing a multispecies approach to the decision-making process, and setting catches and fishing effort on the different fisheries based in a global perspective, where catches on one species can be sacrificed on behalf of a higher economic or ecologic benefit. This is an innovative approach that is being developed in few areas in the world and GadCap supposes the first step to provide with this tool to the NAFO fisheries management capacities.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	331004
Title of Project:	GADCAP— Implementation of a multispecies model GADGET
Name and Title of Coordinator:	

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes 0No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	

RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes 0 No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders		
Experienced researchers (i.e. PhD holders)		1
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**0**
Of which, indicate the number of men:	

D Gender Aspects		
5. Did you carry out specific Gender Equality Actions under the project?	○ ■	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective → Very effective
❑	Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑	Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑	Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑	Actions to improve work-life balance	○ ○ ○ ○ ○
○	Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

■ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

■ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

■ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ○ Main discipline[9]: 1
- ○ Associated discipline[9]:1.4 and 1.5 | ○ Associated discipline[9]:

G Engaging with Civil society and policy makers

11a	**Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	■ ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ■ Yes, in communicating /disseminating / using the results of the project

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ■	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ■ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ■ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

[9] Insert number from list below (Frascati Manual).

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise ***Environment** External Relations External Trade ***Fisheries and Maritime Affairs** Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

○ Local / regional levels

○ National level

○ European level

■ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**2**
To how many of these is open access[10] provided?	**1**
How many of these are published in open access journals?	**1**
How many of these are published in open repositories?	**1**
To how many of these is open access not provided?	**1**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ■ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[11]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

[10] Open Access is defined as free of charge access for anyone via Internet.

[11] For instance: classification for security project.

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☐	Increase in employment, or	☐	In small & medium-sized enterprises
■	Safeguard employment, or	☐	In large companies
☐	Decrease in employment,	☐	None of the above / not relevant to the project
☐	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	■

I	Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes   [x] No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes   [x] No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

[x]	Press Release	[x]	Coverage in specialist press
[ ]	Media briefing	[x]	Coverage in general (non-specialist) press
[x]	TV coverage / report	[ ]	Coverage in national press
[x]	Radio coverage / report	[ ]	Coverage in international press
[ ]	Brochures /posters / flyers	[x]	Website for the general public / internet
[ ]	DVD /Film /Multimedia	[ ]	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

[ ]	Language of the coordinator	[x]	English
[x]	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]